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THE WITWATERSRAND

AND

ASSOCIATED BEDS.

C. B. HORWOOD.

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Dr. Hatch
with the author's
kindest regards

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THE WITWATERSRAND

AND

ASSOCIATED BEDS.

BY

C. B. HORWOOD,
Associate of the Royal School of Mines; Fellow of the Geological Society;
Associate Member of the Institute of Civil Engineers.

JOHANNESBURG:
ESSON & PERKINS.

JUNE, 1905.

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THE WITWATERSRAND AND ASSOCIATED BEDS.

INTRODUCTORY REMARKS.

The Witwatersrand beds comprise two formations, the Upper and the Lower Witwatersrand formation. These are conformable, and the division, being purely an arbitrary one, is placed at the base of those conglomerates known as the Main Reef series.

It is this series which contains the pay gold of the district; and which, owing to the great persistency of its average gold contents over large distances (some fifty miles along the strike) has made the Rand famous throughout the world.

Under the heading of Associated Beds, I include the Old, or Basement Granite; the Swaziland series; and the three formations overlying the Upper Witwatersrand formation, which include, enumerating them from below upwards, the Ventersdorp or Vaal River series, the Black Reef series and the Dolomite formation.

These formations may be said to be associated, because while the Upper Witwatersrand beds outcrop at the surface from Boksburg on the east to Krugersdorp on the west, a distance of thirty miles, much of the eastward extension beyond Boksburg is hidden by overlying strata including the Coal-Measures; and some distance to the south-west of Krugersdorp the extension is masked by the overlying Black Reef series and Dolomite. Hence, in

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exploring for the Main Reef series on the far East or far West Rand, resource has to be made to deep boring; and a knowledge of the overlying formations becomes essential for the intelligent carrying on of such work.

The Coal-Measures alone offer a vast field for research; very much work has already been done on them; and, I do not propose here to give them more than passing notice.

I intend also to include under "Associated Beds" the New, or Red, Granite. My reasons for doing so are: that although it occupies a considerably higher horizon than the foregoing formations, yet to do so it broke through them; because certain bands of syenite encountered in the Dolomite in deep boreholes on the far East Rand have been strongly suspected (†) of being connected with the Red Granite; and, because in studying the Old, or Basement, Granite it is both interesting and instructive at the same time to compare it with the newer or Red Granite.

Before proceeding, it will be well to mention briefly the remaining formations of the Transvaal.

From the Dolomite upwards these include the following:—

1. The Pretoria formation, consisting of quartzites, frequently ripple-marked; sandstones; and ferruginous shales; and, containing numerous dykes and sheets of diabase.

2. The Plutonic series of the Bushveld, consisting of a complex of eruptive and intrusive igneous rocks including acid; intermediate and basic types, as, for

(†) F. H. Hatch. Trans. Geol. Soc. S.A., vol. VII, part II, p. 64.

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example, the Red Granite; various Syenites and Granophyres; Norites, Gabbros, Pyroxenites and Peridotites. Owing to the remarkable fact that this series occupies an almost constant horizon between the Pretoria and Waterberg formations, it has been assigned by Dr. Molengraaff, late State Geologist to the South African Republic, a place among the formations of the Transvaal.

3. The Waterberg formation, consisting of quartzites, conglomerates, sandstones, and ferruginous shales.

4. The Dwyka series. This is a glacial deposit, and consists of fine sediments and coarse breccias—the remains of a former vastly extensive ground moraine. Recent investigations (†) suggest that certain seams of coal may, perhaps, be assigned to this series, and if so, are consequently of interglacial age.‡

5. The Coal-Measures, comprising, from below upwards the three following sub-divisions, in any of which seams of coal may occur :—

   (a) The Ecca beds, which were presumably deposited during the period of retreat of the glaciers. These consist mainly of black, grey, and white sandstones, clays, and shales. The grey sandstones often exhibit beautiful examples of false bedding.

(†) G. S. Corstorphine, Trans. Geol. Soc. S.A., vol.VI, part II, pp. 16 to 19.
F. H. Hatch, ibid vol. VII, part II, p. 61.

(‡) Personally, I am not of this opinion, and, my study of the subject leads me to the conclusion that the conglomerate sometimes found forming a roof to the coal, as at the Central Colliery, Vereeniging, or occurring interstratified with the coal, is of fluviatile origin, and consists mainly of waterworks débris of Dwyka breccia.

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(b) The Beaufort beds, consisting mainly of coarse sandstones. These, characterised by their mural mode of weathering, may be seen, well developed, in the Balmoral district.

(c) The Stormberg beds. These do not occur in the Transvaal, but I am familiar with them in the neighbourhood of Molteno, in the Albert District of Cape Colony, where they are well developed.

In addition to the foregoing, small patches of recent alluvial wash occur here and there.

In describing the Witwatersrand formations and associated beds, I propose to deal with them especially as regards their macroscopical and petrographical characteristics, their chemical composition and field relations. Within the last ten years, so much work has been done and so much written that I feel somewhat diffident in coming forward with the results of my own investigations and research, and at the most I can only hope to add a small quota to the work already performed; and, in some cases to suggest new relations of facts already observed by others.

The districts to which most of my work has been confined are the Central Rand; the Diamond Fields, about twenty-five miles east of Pretoria; certain portions of the Bushveld; Balmoral, some fifty miles east of Pretoria; the district between Johannesburg and Pretoria; Vereeniging district; the far East Rand; and some of the northern portions of the Orange River Colony.

In these two last-mentioned districts my work has been chiefly in connection with deep boreholes, varying from

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1,000 to 5,582 feet (†) in length. I have also examined a very great number of sections under the microscope, embracing nearly every typical rock found in the Transvaal.

With the exception of the Red Granite, I propose to deal with the newer formation first, and work downwards.* The Red Granite and the Basement Granite I shall deal with last, under the heading of Granites.

Authorities and references I have given, where necessary, at the end of the book, opposite the numbers corresponding to those given in the text. §

When reference is made to the Southern Transvaal, that portion of the Transvaal is meant which is included in Dr. Hatch's Geological Map of the Southern Transvaal, revised edition, 1903.

Except when otherwise stated, all analyses were made for me by Messrs. H. Eckstein & Co. (††) Johannesburg, from typical unweathered samples taken by myself; and, they also determined the specific gravities and corrected them for a temperature of 15°.5 C. They informed me that there was no moisture in any of the samples, with the exception of the one of Red Granite from the farm Roodepoortje [149].

(†) During the past two years I have examined over 32,000 feet of core from boreholes in different parts of the Transvaal and Orange River Colony, including rock from every formation occurring in the Transvaal, with the exception of the Swaziland series and the Old Granite.

(*) The portion included under the heading of "The Dolomite Formation" forms the substance of a paper to be read by me before the meeting of the British Association in Johannesburg next August.

§ Reference numbers are in round, farm numbers in square, brackets.

(††) With the exception of that of the Red Granite from Roodepoortje these analyses were all done by B. Bay, Esq., Ph. D.

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The areas covered by the different formations have been calculated by means of the planimeter from Dr. Hatch's map in the case of the Southern Transvaal; and those in other portions of the country from Dr. Molengraaff's geological map of the Transvaal.

For the most recent works on the geology of the Transvaal and South Africa I would refer the reader to the "Geology of the Transvaal," by Dr. G. A. F. Molengraaff, English edition, with geological map, 1904, published by Esson and Perkins, Johannesburg; and to "The Geology of South Africa," by Drs. Hatch and Corstorphine, now in course of publication by Macmillan & Co., London. This latter work contains an excellent bibliography of South African geological literature; and, another by Walcot Gibson, published in the Journal of the Geological Society, vol. 48, pages 406 to 408, is also useful.

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The Dolomite Formation.

Dolomite is the name applied, after the French geologist Dolomieu, to granular magnesian limestone having a crystalline texture. The Dolomite formation of the Transvaal is overlaid conformably by the Pretoria formation, and rests conformably on the Black Reef series. Generally speaking, in each case, there is a more or less gradual passage from the one to the other, and the junctions are not sharply defined.

In the Southern Transvaal, it covers an area of over 2,100 square miles; and the angle of dip is almost invariably a low one. I cannot do better than describe its distribution in this portion of the Transvaal in almost the same words already used by Dr. Hatch (14) for this purpose:—The Dolomite and its accompanying cherts bulk more largely among the rocks of this district than perhaps any other formation. The most northerly belt has its northern margin immediately south of Pretoria, while its southern margin is separated from the granite by a narrow strip of Black Reef formation, the junction of the latter with the granite being a faulted one. The dip is to the north, the beds constituting the northern limb of an anticline, the southern limb of which is found some 10 miles south of Johannesburg. The two belts come together at Wonderfontein, 20 miles south-west of Krugersdorp, the older beds disappearing entirely under the Dolomite arch. Twenty miles farther west they reappear and separate the Dolomite again into a northern belt with a northerly dip, and a southern belt with a southerly dip. The southern belt can be followed to the Vaal River, which it crosses a few miles south-east of Klerksdorp. South-east of Johannesburg the southern limb of the Dolomite anticline circles round and, striking

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south-west, forms the valley of the Klip River, and finally passes under the Karoo formation at Vereeniging. A narrow band of the Dolomite forms the outer ring of the southerly-dipping beds round Venterskroon. According to its dip, it would appear to underlie the quartzites and conglomerates of the Witwatersrand beds that occur here; but its anomalous position is, as Dr. Hatch (14) has already pointed out, due to reversed faulting. The Dolomite also occupies large areas in the eastern, northern and western Transvaal. In the eastern and northern Transvaal it covers an area of some 4,200 square miles. Near Springs the Dolomite, trending in a south-easterly direction becomes hidden by the overlying Coal-Measures, from which it emerges in the district lying to the south-east of Machadodorp and to the south-west of Barberton. Here it is striking north, and stretches away through Godwan and Pilgrims Rest until, near the junction of the Olifant's River with its tributary the Steelpoort River, it bends round to the north-west, and finally curving round to the south-west at the foot of the Chuniesberg, soon becomes lost under the Bushveld Amygdaloid of the Springbok Flats. In the western Transvaal, it forms a big semi-circle, covering an area of about 2,500 square miles. From Ventersdorp it trends in a westerly direction as far as Lichtenburg; it then bends northwards through Malmani and Lobatsi, until near Ramutsa it bends round to the east past Apjater's Kop and beyond Bier Spruit, until some fifty miles south-west of Nylstroom it disappears under the Plutonic series of the Bushveld; and thus its junction with the western arm of the dolomite of the northern Transvaal, already described, is hidden by some eighty miles of overlying beds. Thus the total area covered in the Transvaal by this formation is about 8,800 square miles. In the eastern, northern and western Transvaal, the dolomite dips inwards at a low angle, varying from about 10° to 35°, towards the Bushveld.

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Dr. Molengraaff (50) estimates its thickness at 2,600 feet in the basin of the Witwatersrand; 5,000 feet in the neighbourhood of Pretoria; 1,650 feet near Godwan; 2,600 feet in the vicinity of Lydenburg; and 4,000 feet in the Makapan mountains. Dr. Hatch (15) estimates its thickness at from 6,000 to 8,000 feet. As encountered in boreholes on the far East Rand, its thickness varies from 400 feet in the De Rietfontein No. 1 borehole to 1,100 feet in the Joint Grootvlei-Daggafontein borehole, and its dip varies from about 6° to 10°.

Where the dolomite does not outcrop at the surface, it is, in this latter district, overlaid unconformably by the Dwyka Conglomerate.† This is a glacial breccia, probably of Permian age, the remains of a former ground moraine of vast extent, which occurs at the base of the Coal-Measures, and may be looked upon as the "farewell rock" of the South African coal miner.

The Dolomite, especially in its upper portions, contains a great deal of chert in the form of lenticular bands, boulders, and nodules, reminding one of the flint nodules which are so abundant in the chalk of the Cretaceous formation in England. Indeed, the outcrop of the upper portion of this formation is often quite conspicuous from the presence of numerous chert boulders, which can frequently be recognised from a long distance owing to the way they glisten in the sun. These boulders vary in colour from white or dull blue to a dirty yellow. The colour of the Dolomite itself varies from a bluish-grey,

† The Dwyka, sometimes representing a true ground moraine and sometimes a drift deposit, has covered not only the whole of the Southern Transvaal, but all the South African continent lying to the south of this. It would seem that it can be correlated both with the Talchir Conglomerates of India and with the glacial deposits of Australia; and if so, the glacial deposits of South Africa, of India and of Australia are of contemporaneous origin. *Vide* G. A. F. Molengraaff's—The Geology of the Transvaal (1904), pp. 73 and 74.

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somewhat like that of the mountain limestone of England, to a dull brownish-grey, this latter colour being due to the presence of a little oxide of manganese.

The Dolomite may be described as a massive rock, for although it was, undoubtedly, originally a stratified deposit, it has lost almost all signs of stratification owing to dolomitisation, and to the great amount of secondary silicification it has undergone. Stratified layers of shale and slate are, however, occasionally met with in the formation. In many places it presents a curiously wrinkled appearance, due to uneven weathering, the more siliceous portions standing out in relief. On this account it has won from the Boers the name of Olifantsklip (Elephant Stone), owing to a slight resemblance it then bears to the skin of an elephant. This curious appearance can be well seen between Olifantsfontein and Ashbury stations, in travelling by train between Johannesburg and Pretoria.

A very remarkable outcrop of dolomite occurs on the Zuikerbosch River, about three miles east of Vereeniging. Here the dolomite is in layers which present curious curvilinear outlines, presenting a "saddleback" appearance. The reasons for this I have, so far, been quite unable to explain; possibly, it may be due to some peculiar form of crystallisation. The nature and general appearance of the outcrop is well shewn at the end of this book in Plates I. and II., from photographs taken by Mr. T. N. Leslie, which he has kindly allowed me to reproduce.

As regards its scenic aspect, speaking generally, it consists of gently undulating grass country with few trees. Its lower beds are frequently largely hidden by surface soil, a few rounded boulders, often exhibiting the typical corrugated appearance, which has made the

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rock known to the Boers as Olifantsklip, appearing here and there. In its upper layers characteristic escarpments occur, due, as Dr. Molengraaff (52) has pointed out, to the greater amount of chert in these layers, and the consequent greater resistance to even weathering. These features may be well studied as one travels by train from Johannesburg to Pretoria. Soon after passing Olifantsfontein station, a few rounded boulders of Olifantsklip begin to appear, and the country presents the appearance of a grassy upland with few or no trees. As Pretoria is approached, and the upper portion of the Dolomite formation is being traversed, the country gradually becomes slightly hilly, until near Ashbury station we have escarpments and, more or less, hummock-shaped hills, sparsely covered with low scrub and thorn bushes.

From numerous sections of dolomite, which I have examined under the microscope, I have found it to be very fine-grained, crystalline and compact; and only here and there can crystals be distinguished shewing the characteristic polysynthetic twinning of calcite or dolomite, except where recrystallisation has taken place at the marmorised junctions with intrusive igneous rocks. Frequently, at these junctions it is serpentinised or graphitic material is developed, in which cases it is not marmorised.

In one borehole, No. 4, on the farm Palmietkuil [61], between the depths of 130 and 696 feet, the rock, which normally should have been all dolomite, consisted of 169 feet 1 inch of dolerite, 108 feet 11 inches of tonalite, 183 feet 5 inches of dolomite, and 104 feet 7 inches of serpentine and serpentinous dolomite, occurring in four, two, three, and three separate bands respectively. From 696 feet to 1,257 feet 6 inches, a dolerite dyke was encountered, which cut out the lower portion of the Dolomite, the Black Reef quartzite, and the lower portion of the Upper Witwatersrand beds. The serpentine was developed as a

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result of the alteration of the dolomite owing to contact metamorphism, due to the intrusive sheets of tonalite and dolerite, and to the presence of the dolerite dyke.

Diabase dykes occur, in a few places, in the formation, as for example at the foot of the Ikalafyn hill, in the Malmani district (72).

Dr. Hatch (16) mentions the occurrence of two interesting dykes, which strike north and south at Wonderfontein, some twenty-two miles south-west of Krugersdorp. They are quarried for ornamental building stone. He describes a section from the western dyke as showing, under the microscope, porphyritic crystals of orthoclase, plagioclase, and augite embedded in a holocrystalline and granophyric groundmass of quartz and felspar; and, calls it a granophyric syenite; and, describes the eastern dyke as being of similar composition but containing no quartz; and consisting of green augite, brown mica and large lath-shaped crystals of orthoclase felspar; and, terms it an augite syenite. Petrographically, therefore, this rock is very similar to the tonalite described below and may probably be connected with it in origin.

As already pointed out by Dr. Hatch (19), a remarkable feature of the Dolomite formation on the far East Rand is the presence of several sheets of a red or grey igneous rock, which he terms a syenite. These sheets are wonderfully persistent over a large area, being cut, at practically the same horizon in boreholes many miles apart; they vary in thickness from 10 to 125 feet, and in number from one to five in any one borehole, the total thickness varying from 100 to 180 feet. The microscopical features of this rock have also been fully described by the same author (20).

The following is the result of an analysis I have had made of a typical sample of this rock taken from between

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the depths of 525 and 585 feet from No. 2 borehole on the farm Palmietkuil [61] on the far East Rand:—

SiO_2	62.20
TiO_2	—
Al_2O_3	16.58
Fe_2O_3	5.00
FeO	2.80
MnO	tr.
CaO	4.40
MgO	4.20
K_2O	1.80
Na_2O	2.10
P_2O_5	0.37
FeS_2	0.17
H_2O	—
	99.62

Sp. Gr. 2.686.

Dr. Molengraaff calls this rock a tonalite, while Dr. Hatch terms it a syenite. The percentage of silica places it in the category of intermediate rocks. The quartz is subordinate and interstitial; a little orthoclase is present, yet plagioclase is more abundant, and, it contains less potash than soda; it is a holocrystalline rock consisting essentially of plagioclase, magnesia-mica, and hornblende; with a little orthoclase and some interstitial quartz; therefore, the former of the two nomenclatures is, perhaps, the more appropriate. As I intend to discuss this rock at length, later on, under the heading of Granites, I will not say more about it here.

Almost equally persistent in the same district are certain narrow bands of a black rock, having the appearance of an impure graphite and possessing the greasy lustre so characteristic of Ceylon and other graphites. In section under the microscope it is mostly cryptocrystalline and indeterminable, much of it being quite opaque; but, here and there, portions of it are seen to be largely composed

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of microcrystalline angular quartz particles. These bands vary from less than half an inch up to about a foot and a half in thickness. Thus in the joint borehole on Daggafontein [94], where they were rather well developed, between the vertical depths of 166 feet and 927 feet seventeen bands were encountered, which varied in thickness from ¾ of an inch to 17 inches; and represented a total thickness of 9 feet 10¼ inches. In the same hole, in addition to the above, between the depths of 303 feet 5 inches and 305 feet 6 inches, a band of this rock 2 feet 1 inch thick occurred, which was much mixed with dolomite. Four bands of dolomite of very graphitic appearance were also intersected. These were 27 feet 10 inches; 16 feet 3 inches; 1 foot 8 inches; and 1 foot 1 inch thick respectively, and represented a total thickness of 46 feet 10 inches.

I have had an analysis made of the band occurring between the depths of 486 feet 5 inches and 487 feet 10 inches. Only 13 inches was recovered, 4 inches having been lost in drilling. The diameter of the core obtained was 2 inches.

The following is the result of the analysis:—

SiO_2	74.58
Al_2O_3	15.10
Fe_2O_3	1.28
FeO	—
MnO	—
CaO	0.50
MgO	1.44
K_2O	0.70
Na_2O	1.00
FeS_2	0.812
C	2.65
Loss on ig.	1.35
	99.412

Sp. Gr. 2.671.

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This particular band was selected for analysis as being fairly representative of the occurrence as met with, in the Dolomite formation, in widely separated parts of the country; it may, perhaps, be best described as a graphitic shale.

It is interesting and instructive, to speculate on the source from whence the carbon is derived. Apparently, these bands mark successive periods in which vegetation, to some extent, flourished during that geological era in which the deposition of the dolomite occurred. If, as Dr. Hatch (22) seems to think, the dolomite is a shallow and not a deep sea deposit, one can understand how, either by successive elevations and depressions of the shore and the growth of land flora during the periods of elevation, or by accumulations either of vegetation brought down by rivers or of seaweed, such deposits could occur.

Below in Column I. is given the result of an analysis of a typical specimen of dolomite as encountered in boreholes on the far East Rand. The sample is from No. 2 borehole on the farm Grootvlei [176], and is taken from a depth of over 200 feet from the surface:—

	I.	II.
SiO_2	15.29	0.94
Al_2O_3	tr.	—
Fe_2O_3	1.20	—
FeO	0.43	1.35
MnO	tr.	1.18
CaO	29.20	29.61
MgO	12.45	19.71
K_2O	0.38	—
Na_2O	0.98	—
FeS_2	0.62	—
CO_2	38.82	46.69
H_2O	—	
	99.37	99.48
Sp. Gr.	2.874	2.88

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From this analysis the percentage proportions of calcium and magnesium carbonates present are 52.14 and 26.14 respectively, which account for the presence of 36.64 per cent. of carbon dioxide. Dolomite, when pure, consists of 54.35 per cent. of carbonate of lime, and 45.65 per cent. of carbonate of magnesium. This rock would, therefore, be more accurately described as a magnesium, or dolomitic, limestone.

The total insoluble residue present is 15.29 per cent.; and, the silica accounts for the whole of this amount. Mr. A. Heymann, chief analytical chemist to Messrs. H. Eckstein & Co., informs me that he has made numerous analyses of samples of dolomite from various parts of the Transvaal; and, has found that in every instance there is a high percentage (never less than 2 per cent.) of insoluble residue present.

Analysis No. II. is that given by Dr. Hatch (16), and made by Mr. G. T. Prior of the Mineralogical Department of the British Museum. Dr. Hatch does not state from whence the sample was obtained. The percentage proportion of calcium carbonate is 52.87, and of magnesium carbonate 41.39. The same author (16) also states that "certain portions of the dolomite are highly impregnated with silica; and almost every gradation appears to exist between dolomite and chert."

A striking feature in these analyses is the variation in the amounts of silica and magnesia present. In the one case there is over 14 per cent. more silica present than there is in the other, while the percentage proportion of magnesium carbonate is over 15 per cent. less. The percentage proportion of calcium carbonate is practically the same in each case. From this it would seem that where secondary silicification of the dolomite has occurred, it has taken place at the expense of the magnesium

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carbonate, the latter having been removed in solution and the silica having been precipitated.

Like the limestones of England and elsewhere, the Dolomite contains numerous fissures and caverns which may have been produced by the solvent action of meteoric water charged with carbon dioxide, or by a process of dolomitisation. Élie de Beaumont (10) has calculated that, on the assumption that one out of every two equivalents of carbonate of lime was replaced by carbonate of magnesia, the conversion of limestone into dolomite would be attended with a reduction of the volume of the mass to the extent of 12.1 per cent. If, therefore, the dolomite be not an original chemical precipitate from the saline water of an inland sea or lake but a product of alteration such as might, for example, arise from the alteration of an ordinary limestone, then these fissures and caverns may be due to contraction during the process of dolomitisation; or, it is quite possible that they may owe their origin to a combination of both of the above causes. These cavities serve as underground channels and reservoirs for water, and are frequently a source of trouble in boring operations owing to the ground caving in. Of the caves occurring in the dolomite, the Sterkfontein caves, some few miles to the north of Krugersdorp, are, perhaps, the most famous on account of the beautiful stalactites which they formerly contained; but, which have since been destroyed by visitors. There are also numerous caves on the farm Wonderfontein, near Oberholzer Station, between Krugersdorp and Potchefstroom, some of which are of great size. The main gallery of one of them has been lately explored for 7,000 yards, and still the end was not reached. For a good account of these caves and a description and analyses of the accumulated deposits of bones, and also of bat guano, I must refer the reader to an article by Herbert Ingle, published in the "Transvaal Agricultural Journal" for January, 1905.

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Other less-known caves such as Wondergat, near Donkerpoort, and Makapan Gat to the east of Piet Potgietersrust, are to be found in this formation in several localities.

Economically, the Dolomite formation is chiefly important as being, practically, the only source of water supply which the country possesses, if one omits conserved rain and surface water. Dr. Molengraaff (53) has already pointed out that nearly the whole of the perennial rivers of the western half of the Transvaal owe their existence to the remarkably constant springs which occur in this formation, owing to the water from the heavy rains during the wet season, from December to March, filtering rapidly into the rock fractures and caverns which are so abundant in the Dolomite, and which constitute a network of reservoirs of immense capacity. Up till now, one of the chief sources from which Johannesburg has derived its water has been the dolomite on the farm *Z*uurbekom, about 18 miles south-west of the town; this has been well described in a paper read by Mr. David Draper (8) before the Geological Society of South Africa. At the beginning of 1903, the average daily consumption of water in Johannesburg was estimated at 800,000 gallons (46); and, it is estimated (49) that the average daily requirements for Johannesburg and the Witwatersrand District, including the mines, for the year 1906 will be 12,771,200 gallons; and, 20,000,000 gallons for the year 1909. As in the past, so in the future, practically the whole of the supply will be obtained from the Dolomite formation.

Moreover, the dolomite, and more especially the more or less pure limestone which is found here and there associated with it, as for example at Irene, are the source whence most of the quicklime used in the Transvaal is obtained; hydraulic lime of fair quality is also, I understand, manufactured from the dolomite.

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The minerals found in this formation include gold, occurring in quartz in fissure veins, as for example at Malmani; galena, as at Kromdraai (7) where it occurs in a quartz reef in association with a very persistent bed of shale near the base of the formation; and, I am informed by Mr. A. R. Sawyer that small amounts of native copper are found near Chunies Poort, about 20 miles south of Pietersburg; manganese, and smaller quantities of a few other minerals also occur. However, up to the present, none of these have been exploited with any great success. Later on, it is possible that its undoubtedly good qualities as a road metal may be recognised; and it may then be used for macadamising the streets and roads of Pretoria, Johannesburg and other towns.

A remarkable feature of the formation is that, up to the present, no undoubted proof of a single organism has been forthcoming. This is, probably, due to obliteration of organic structure due to the dolomitisation of what was probably a limestone, consisting largely of organisms. Owing to this, and to the entire absence of fossils, so far as our present knowledge goes, in any of the formations older than the Coal-Measures, by which they are overlaid unconformably, it has been impossible to do more than speculate as to the age of either this, or of any of the formations older than the Dwyka Conglomerate.

The high percentage of insoluble residue in the Dolomite and the amount of silicification which it has undergone indicate a deep sea, and not a "coral reef," origin (74). Although the somewhat great thickness of the deposit does not, taken by itself, altogether support this view. If of deep sea origin, dolomitisation probably took place in shallow water, during the subsequent gradual elevation of the sea-

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bottom. The limestone being more or less porous, an interchange could take place between the magnesium salts in the sea water,† containing carbon dioxide under pressure, and the calcium in the limestone. In this connection, it is interesting to note that Professor E. W. Skeats (74) has shewn that shallow water between the surface and 150 feet in depth, corresponding to a pressure of 1 to 5 atmospheres, is especially favourable to the process of dolomitisation.

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† The amount of magnesium present in the waters of the ocean has been calculated to be about 0.14 per cent. (*Vide* Bull. U.S.G.S. No. 78 (1891), p. 35.)

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The Black Reef Series.

In the Southern Transvaal this formation extends over an area of approximately 180 square miles. In the Western Transvaal it covers about 460 square miles, and in the Eastern and Northern Transvaal some 480 square miles; in all, over 1,100 square miles. The thickness of the series, as given by Dr. Molengraaff (51), is under 100 feet in the Witwatersrand district, and at Klerksdorp; and in other districts it varies up to 1,640 feet.

Its outcrop forms a narrow margin on the outer edge of the Dolomite, characterised both by its narrowness, and by the winding sinuous course which it assumes. This is perhaps more particularly noticeable on a geological map than in the field.

As regards the scenic aspect of this formation, Dr. Molengraaff (54) describes it as forming often a slightly elevated and more or less wooded escarpment, in contrast with the plains, which are nearly everywhere devoid of trees.

The Black Reef series everywhere conformably underlies the Dolomite, the two merging into each other so gradually that in several boreholes I have often found it very difficult, and sometimes impossible, to decide exactly where the one begins and the other ends. On the far East Rand, as already pointed out by Dr. Hatch (19), the Black Reef series is only poorly developed, being represented merely by a bed, about 20 feet thick, of a very dense black quartzite. In the district known as the West Rand Extension it is also only represented by a thin band of quartzite. In the former district, numerous deep boreholes, measuring from over 1,000 feet up to more than a mile in length, have been put down with the object of locating the Van Ryn

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Reef, which is correlated with the Main Reef of the Central Rand. In these boreholes this quartzite has been passed through at various depths, but usually at less than 1,000 feet from the surface; and yet it is one of the hardest rock encountered by the drills, and is harder than the quartzites of the Upper Witwatersrand beds occurring three or four thousand feet deeper, and which, having the weight of this extra thickness of overlying beds above them, one might, therefore, expect to be denser and more compact.

In one of the above boreholes, two bands of conglomerate occurred in this quartzite. These were 2½ and 9½ inches thick respectively; the former was very pyritic, and the pebbles in it were small; the latter was only sparsely pebbled. Also, in another borehole, in the same neighbourhood, a band of Black Reef conglomerate 9¼ inches thick was passed through. This consisted of small white sub-rounded and angular quartz pebbles, up to about 1 inch in greatest length, imbedded in dense black quartzite; the whole was very heavily pyritic, the pebbles in cases being surrounded by pyrites, which occurred as layers round the pebbles, dividing pebble from pebble. It contained only a trace of gold.

In the hand specimen, this quartzite is black in colour, heavy, crystalline, granular, compact and possesses a somewhat saccharoidal texture and breaks with a lustrous fracture. As pointed out by Sir A. Geikie (12), this lustrous fracture, observable in many quartzites, is doubtless due to the exceedingly firm cohesion of the component grains, which break across rather than separate, and the consequent production of innumerable minute clear vitreous surfaces of quartz.

From sections which I have examined under the microscope, I find it consists of a closely packed mass of

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small quartz granules. These are mostly sub-rounded, but some are angular. They vary somewhat in size, and around them in some cases a small amount of secondary silica has been formed, while here and there this secondary silica can be seen cementing the quartz particles together. Interstitial granules of quartz, which are only discernable under the microscope, and a little interstitial, dark, indeterminable matter, together with a little iron pyrites, is also present.

Below in Column I. is the result of an analysis I have had made of this rock from a sample from No. 2 borehole on the farm Palmietkuil [61], in which this quartzite occurred between the depths of 752 feet 6 inches and 755 feet 8 inches.

	I.	II.	III.	IV.
SiO_2	96.40	96.57	87.60	73.64
~~TiO_2~~*	.....	.....	.....	tr.
Al_2O_3	tr.	tr.	8.20	11.25
Fe_2O_3	1.22	1.72	0.99	6.24
FeO	tr.	—	—	1.04
MnO	tr.	—	—	—
CaO	tr.	—	tr.	0.36
MgO	tr.	tr.	1.00	1.57
K_2O	0.12	0.67	0.98	1.42
Na_2O	0.60	0.82	1.10	3.04
FeS_2	0.82	tr.	tr.	—
Loss on ig.	—	—	—	1.98
	99.16	99.78	99.87	100.54
Sp. Gr.	2.643	2.660	2.685	

Column II. shews the analysis of a typical coarse white crystalline quartzite of the Upper Witwatersrand formation. The specimen was taken from a depth of

* A dotted line (...) indicates that the constituent against which it is placed has not been sought in the analysis.

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3,123 feet from the Grootvlei-Daggafontein joint borehole on the far East Rand. This rock contained a small amount of sericite, was very uniform in texture and general appearance, and broke with a lustrous fracture.

The analysis in Column III. is that of one of the typical soft sericitic grey quartzites, or quartz schists, which occur in the Upper Witwatersrand formation. The specimen was taken from the same borehole as that in Column II., from a depth of about 2,085 feet.

Column IV. gives the composition of a typical quartzite from Pigeon Point, Minnesota, and was published in the Bulletin of the United States Geological Survey. No. 168, page 78, and quoted by Sir A. Geikie (11) as an example of a typical quartzite.

The Black Reef quartzite differs very slightly in chemical composition from the coarse white crystalline quartzite of the Upper Witwatersrand formation. The percentage of silica in each is practically the same and there is only half per cent. more ferric oxide in the latter than in the former; they contain none, or only traces of ferrous oxide, alumina, lime, and magnesia; and, they are both very low in alkalies; but while the latter contains no manganese, and only a trace of ferric sulphide, the former contains a trace and 0.82 per cent. respectively. Probably, it is to this trace of manganese that the Black Reef quartzite owes its persistent black colour. Possibly, this manganese is of secondary origin and has been derived from the Dolomite by descending solutions. Both of these rocks, viz.: the Black Reef quartzite and the coarse white crystalline quartzite of the Upper Witwatersrand formation differ very considerably from the other two, of which the analyses are given above, the main differences being the smaller percentages of silica, and the amounts of alumina present in the two latter. The sericitic quartzite,

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which is of a somewhat schistose character, forms an intermediate type between the first two and the typical quartzite from Pigeon Point. It contains a lower percentage of silica than either of the former, though higher than that of the latter rock; the amount of alumina present is as high as 8.2 per cent., and though still only containing a trace of lime, it has 1 per cent. of magnesia, and the amounts of the alkalies are greater than they are in either of the first two analyses. In the first two rocks, there has apparently been an increase in the percentage of silica, at the expense of the alumina, iron, lime, magnesia, and alkalies, due probably to a process of secondary silicification. Both rocks in section under the microscope exhibit a secondary growth of quartz here and there, which has been developed round the edges of the quartz granules, and is absent in the micaceous quartzite. In the latter, the matrix consists of an admixture of mica and quartz; and the microscope reveals a well-defined schistose structure. In the first two rocks, this structure is absent, and the matrix is quartzitic. It is necessary to bear in mind that quartzite is really a metamorphosed sandstone, which has become compact and indurated either by pressure alone; or, more frequently, by the deposition of silica between the granules; or, by a slight solution of these granules by permeating water, so that they have become mutually coherent; or, by a combination of these causes. In the case of the quartzites of the Upper and Lower Witwatersrand formations, pressure has undoubtedly played a very important part. Consider, for example, the Witwatersrand Syncline (see Section). Pressure has here been exerted in a north and south direction, the strata have been bent in the form of a syncline and strike east and west; but the Witwatersrand beds have been influenced far more by this pressure and dip at a much steeper angle than those of the Black Reef series which are situated at a higher geological horizon in the upper

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portion of this synclinal basin. It would seem, therefore, that secondary silicification, due to heated siliceous waters rather than to pressure, has played a more important rôle in the formation of this Black Reef quartzite than it has in those of the Witwatersrand formations. This conclusion would, in a measure, account for the unusually high percentage of silica in the above analysis to the partial or entire exclusion of alumina, iron oxides, lime, magnesia, and the alkalies, though doubtless this is mainly due to the higher percentage present in the original sandstone. (†) In the case of the two rocks of the Upper Witwatersrand formation, the metamorphism may probably be chiefly ascribed to pressure, and only in a lesser degree to secondary silicification, due to ascending solutions; and the difference in the percentages of silica to the composition of the original sandstone.

Summarising, we may say that the Black Reef quartzite differs from the quartzites of the Witwatersrand formations by some, or all, of the following characteristics, as the case may be :—Its greater hardness; its persistent crystalline nature; the roundness of its individual granules and their close juxta-position, as revealed by the microscope; the presence of a trace of manganese; the absence of sericite and talc; and the absence of a tendency to a schistose character, and its very high percentage of silica as compared with some of the quartzites of the Witwatersrand beds.

So far we have been confining most of our attention to the typical Black Reef quartzite, which after the reef or conglomerate itself is the most characteristic member of this formation. Considering now the series in general, as briefly described by S. J. Truscott (75), it consists of an underlying reef of banket, from a few inches

(†) This suggests that the Black Reef series has probably been derived from the denudation of the Witwatersrand beds.

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to 14 feet in thickness, separated from the underlying amygdaloidal diabase by a few inches of dark ferruginous clay, and overlain by alternations of quartzites and shales having a total thickness of from 30 to 75 feet, which are again overlaid by a bed of quartzite varying from 10 to 100 feet in thickness. It is owing to this underlying dark ferruginous clay that the name of "Black Reef" has been given to this formation.

The presence of this basal bed of banket was formerly regarded as the most important feature of this formation owing to the fact that in many localities it was gold-bearing. Numerous mines were started and worked on it, as for example the Orion, Minerva, Vesta, and the Meyer and Leeb near Natal Spruit, the Eastleigh at Klerksdorp, and the Midas Estate on the farm Middlevlei to the south of Randfontein. All these mines have long since stopped working. Unfortunately, it was found that although rich values and rich chutes occurred here and there, the average value throughout any one mine was too low for profitable working. S. J. Truscott (76), describes the conglomerate as a hard siliceous banket, of which the pebbles are usually small, and says that the lowest portion is generally well mineralised with pyrites, and contains fragments of the amygdaloidal diabese on which it rests.

The Black Reef Series overlies unconformably the older formations. In boreholes on the far East Rand it immediately overlies the Upper Witwatersrand beds. At Teankop, in Bechuanaland, about 60 miles west of Vryburg, it can be seen overlying the Old Granite as shown at the end of this book, in Plate III, from a photograph taken by Mr. G. G. Holmes. About three miles east of Vereeniging a very good section is exposed on the left bank of the Zuikerbosch River. Here the typical Black Reef quartzite is seen overlying the

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Klipriversberg Amygdaloidal Diabase. This is illustrated in Plate IV, from a photograph kindly taken for me by Mr. T. N. Leslie. Both formations dip at an angle of some 10 degrees in an easterly direction. The diabase is decomposed and altered at the contact for a thickness of about a foot into a fissile schist of a light grey colour. This alteration is very likely due to surface cooling and subsequent weathering influences before the deposition of the Black Reef formation. About 4 feet 6 inches above the contact, there is a band of black shale, 8 or 9 inches thick, interbedded with the quartzite. Large amygdules occur in the diabase close to the junction with the quartzite. I measured one right at the contact, which was 12 inches by 9 inches. This in itself, quite apart from numerous other considerations, clearly indicates that the Black Reef series is younger than the diabase, otherwise we should expect the latter to be fine-grained and not vesicular at the immediate contact.

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The Ventersdorp or Vaal River Series.

This series occurs in the Southern portion of the Transvaal, where it covers an area of over 1,000 square miles. It is older than the Black Reef series, but younger than the Upper Witwatersrand formation. Above it there is unconformity; and also at its base. This formation is considerably more diversified as regards scenery than perhaps any of the other formations of the Southern Transvaal. It is characterised by low ranges of serrated hills and by irregular shaped kopjes covered with grass and low scrub; and, generally, by more or less hilly ground and the presence of igneous boulders.

Until quite recently the only recognised member of the series was the Klipriversberg Amygdaloidal Diabase, so named on account of its strong development some few miles to the south of the Witwatersrand, where it forms a low range of rugged hills, known as the Klipriversberg, through which the Klip River runs. This river has its source in the Dolomite formation on the farm Klipriversoog, adjoining Zuurbekom on the east.

In September, 1903, two short papers were read before the Geological Society of South Africa. One, by Dr. Molengraaff, was entitled "Preliminary Note on a hitherto unrecognised Formation underlying the Black Reef Series." In it the author briefly described certain rocks occurring in the south-western and southern Transvaal, consisting of shales, schists, and shaly conglomerates, banded cherts, amygdaloidal diabase, tufas, grits, and very coarse conglomerates, the correlation of which with the known formations had always been doubtful. Attention was also called to the fact that these rocks may in places be seen unconformably underlying the Black Reef and overlying the Witwatersrand beds unconformably; and, the author stated that he thought there

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was much in favour of the Klipriversberg Amygdaloidal Diabase being a part of this formation.

The other paper entitled "Note on an unusual basal development of the Black Reef Series in the Orange River Colony," was by Dr. Hatch. In it the writer mentions the occurrence, between the Black Reef and Klipriversberg Amygdaloid, of a considerable thickness of coarse conglomerate containing flattish pebbles or boulders of fine quartzite in a very gritty matrix; the beds dipping at an angle of 60°. The particular section described occurs on the farm Stinkhoutboom, near Reitzburg, in the Orange River Colony. After passing over Black Reef quartzites and the Black Reef conglomerate, firstly five feet of closely laminated shale is met with, and then 500 feet of the coarse conglomerate above described, and lastly the Klipriversberg Amygdaloid. Here these beds appear to underlie the Black Reef series conformably; but, as the author points out, this may be only apparent and not real.

Two months later, in November, 1903, another paper, entitled "The Boulder Beds of Ventersdorp, Transvaal," was read by Dr. Hatch before the same Society. In this the author describes certain boulder beds consisting of banket (some auriferous), quartzite, slate and quartz in a coarse gritty matrix consisting chiefly of quartz, and cemented by oxide of iron. He states that the boulders vary greatly in size, some being several feet in diameter; that they have a flattish shape; and, that they consist of ordinary conglomerates and quartzites identical with those occurring on the Rand, and belonging to the Upper Witwatersrand beds; also banded slates, belonging to the Lower Witwatersrand beds; quartz; a coarse-grained gabbro or dolerite; a vesicular diabase; and, a dark-coloured quartz-porphyry; and states that here the boulder beds lie unconformably above the Lower Witwatersrand formation. He then goes on to say that these beds are made

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up of the débris of the older formations, chiefly Witwatersrand beds, and that there is no evidence to fix exactly the place whence the boulders were originally derived; and, that there can be no doubt that these beds belong to the series described by Dr. Molengraaff and himself in their papers which were read the previous September, and he suggests the name of "Ventersdorp Beds" for this series on account of its great development in, and near, the town of that name. Furthermore, he divides the boulder formation of Ventersdorp into two types, a conglomerate type and a breccia type. The former consists of boulders described as completely rounded or water-worn, and consisting chiefly of Witwatersrand conglomerates, quartzites and slates, and the matrix of an aggregation of sub-angular grains of quartz. In the latter the boulders are described as angular blocks shewing no signs of abrasion, and the cementing material as having the structure and composition of a basaltic rock, consisting of a mesh of small lath-shaped crystals of felspar in a ground-mass of magnetite granules, and large patches of a yellowish-brown substance, which perhaps represents a decomposed glass; and this latter type is spoken of as an igneous breccia. The author then gives it as his opinion that both types are connected with a period of great volcanic activity, and that it was during this period that the outpouring of the Klipriversberg Amygdaloidal Diabase occurred, and says that if the big rounded boulders were abraded and deposited by the agency of water, the streams must have been of phenomenal strength and volume.

During the following month, a paper entitled "The Volcanic Series underlying the Black Reef" was read before the same Society by Dr. Corstorphine, late Director of the Geological Survey of the Cape of Good Hope. In this paper attention is called to extensive conglomerate outcrops on Kromdraai, near Krugersdorp,

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which are unconformable to and different from the Witwatersrand beds; also to conglomerate outcrops of the "new formation" unconformably underlying the Black Reef series on the farm Rietfontein [286], on the east of the Pretoria Railway. The author then goes on to state that the region where the real character of the "new formation" first became apparent to him was in the valley of the Suikerbosch Rand River, where the conglomerate beds occur in close association with great masses of diabase, which he describes as being sometimes compact, sometimes slaty, sometimes amygdaloidal, and of the same type as that of the Klipriversberg. He says that the conglomerates are real volcanic breccias, which, like the diabase, have often become sheared and slaty; also that, in his opinion, the diabase of the hills forming the southern boundary of the Fortuna Valley, which geographically and geologically are continuations of the Klipriversberg, is also part and parcel of the same series. He states that on the farm Elandsfontein [281], sheared volcanic breccia forms part of the series. Finally, he says: "The conclusion to which the exposures in the Suikerbosch Rand River lead one is that the 'new formation' is essentially a volcanic one, lying unconformably upon the older Witwatersrand beds, and itself covered unconformably by the Black Reef series. It holds, therefore, the stratigraphical position to which the Klipriversberg Amygdaloid has been assigned, and the association of the Amygdaloid with the slaty diabase and volcanic breccia in the Suikerbosch River Valley is good evidence that when the whole of the 'new formation' is known, we shall have the complete history of that phase in the geological history of the region of which, till recently, the Klipriversberg rock alone was the recognised representative."

Mr. Dörffel (7) also mentions that the Black Reef formation on Kromdraai is deposited unconformably on

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a schistose conglomerate belonging to this "new formation;" and, that the boulders of this conglomerate are mostly of quartzites belonging undoubtedly to Witwatersrand beds.

Later, in a paper by Drs. Hatch and Corstorphine on "The Geology of the Bezuidenhout Valley and the District East of Johannesburg," read before the same Society in August, 1904, the authors describe the amygdaloidal diabase and associated rocks of that neighbourhood. They state that the whole bottom of the valley is occupied by amygdaloidal diabase and diabase-breccia, and that the former belongs to the Ventersdorp series, being of the same type as that forming the Klipriversberg, south of Johannesburg. Attention is called to the outcrop, on the north side of the valley, of unmistakable Ventersdorp beds, consisting of slates, fine quartzites and coarse conglomerates with quartzite pebbles, the latter appearing to pass under the amygdaloid. They then go on to state that the relation between the conglomerates, slates, breccia and diabase does not appear to be a constant one, and that this is only to be expected where, as in this case, long-continued volcanic activity, producing alternate outpourings of lava and the ejection of fragmental material, has accompanied the deposition of true sediments.

Still more recently, in March, 1905, Dr. Molengraaff read a paper before the same Society entitled, "Note on the Geology of a portion of the Klerksdorp District, with Special Reference to the development of the Lower Witwatersrand Beds and the Vaal River System." The author states that in this particular district all strata of the Rand system (*i.e.* Old Granite, Witwatersrand formations and Swaziland series) higher than the Hospital Hill series are covered by rocks of the Vaal River system or by surface deposits. Incidentally, he draws attention

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to the frequent occurrence of cleavage with a dip opposite to the stratification in the lowest portion of the Rand system, and to the fact that the porphyrites belonging to the Vaal River system on Rhenosterspruit [16] are cleaved in the same direction as the strata of the Lower Witwatersrand beds, thus shewing that the earth movements causing the pressure which gave rise to this cleavage took place after the deposition of the beds of the Vaal River system. The author also states that this latter system in this area can be found lying either on granite or on strata of the Rand system; and that many sections can be obtained shewing the unconformity between it and the underlying rocks, and also that the lowest stratum of the system is usually either a breccia with a cement of preponderating igneous material, or amygdaloidal diabase, but that sometimes it consists of porphyrite. A tabulated list of sections of the Vaal River system from various parts of the Transvaal, and from the Kimberley and the Bultfontein Mines, illustrating the diversity which at present appears to exist in the sequence of the strata of this system is given in the paper, which is concluded with the following words: "The era in which the Vaal River system was formed appears to have been characterised by the deposition of coarse sediments repeatedly interrupted or accompanied by gigantic outpourings of lavas and loose volcanic material, both of basic and of acid constitution. It is noteworthy that the conglomerates of the Vaal River system often exhibit a great similarity to glacial conglomerates by reason of their non-stratified appearance, and by the absence of any regularity in the arrangement of the pebbles and boulders; also the pebbles and boulders often have their edges somewhat rounded, but are not flattened or waterworn. The cement, however, is not nearly so fine-grained as is usual in conglomerates of glacial origin, as, for instance, in the Dwyka Conglomerate. Polished or scratched pebbles have not yet been recorded from the Vaal River system conglom-

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erates. Now, although I do not think that the evidence at present available is sufficient to enable one to definitely assert that the conglomerates of the Vaal River system are of glacial origin, still, I think, it is not easy to understand how such conglomerates came to be formed otherwise than by glacial action."

May it not be that these boulders consist, wholly or in part, of fragments of the rocks in which the volcanic vents occur and that their rounding may be due both to trituration during their ascent in these vents, and to subsequent aqueous erosion.

There can be no doubt that the volcanic activity to which we owe this series was spread over a considerable period. The presence of intrusive sheets of amygdaloidal diabase (see page 37 *et seq.*) identical in petrographical habit and macroscopically and chemically with the Klipriversberg Amygdaloid; the numerous diabase dykes on the Witwatersrand; and, the occurrence of fragmental volcanic material in the Bezuidenhout Valley all indicate that one, at least, of the vents from which the volcanic series of the Vaal River system was erupted was situated either in, or in the immediate neighbourhood of, the Witwatersrand basin.

The Witwatersrand dykes consist, almost without exception, of basic rock of the diabase type, usually much decomposed and uralitised. Although the majority are probably of not later date than that era to which we owe the Vaal River system, yet they are not all of the same age, for example, in the Jupiter Mine, (*) a longitudinal or strike dyke is cut by a transverse dyke which has thrown it 180 feet to the north, clearly showing that the transverse dyke is younger than the other. Some may even be as late as Karroo Age.

(*) At present the deepest mine on the Rand, the bottom level being 3907 feet vertically below the surface.

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With regard to the thickness of the Vaal River Series, Dr. Hatch (17) estimates the thickness of the volcanic flows of this series as being at least 5000 feet; and, Dr. Molengraaff (55) at over 2500 feet in the Klipriversberg.

Returning now to the Klipriversberg Amygdaloid, which is the chief member of the series and the one of which it is mainly composed, this attains its greatest development in the Klipriversberg, a range of hills some 5 or 6 miles to the south of, and running parallel to, the Witwatersrand; in the Suikerboschrand Range, which, trending north-east and south-west, extends for some little distance north-west of Heidelberg almost to Vereeniging; as a fringe around the outer edge of the Witwatersrand beds encircling the Vredefort granite boss; and also in the district to the west and south of Klerksdorp, from whence it, together with its associated rocks, can be followed almost to the junction of the Vaal with the Orange River.

In colour, the rock varies from light to dark olive green, the surface weathering to a rusty brown. The most prominent amygdules are of calcite, and these occur in all sizes up to about one foot in greatest length. Smaller quartz amygdules, for the most part not more than an inch or two across, also occur. Sometimes the amygdules are composed of successive growths of calcite and quartz. Iron and copper pyrites also occur both in the matrix and in the amygdules. There are also very numerous small amygdules of chlorite, which usually do not exceed half an inch or an inch in length, and are mostly smaller than this. They are dark green, often almost black, in colour.

Under the microscope, the rock is seen to consist of a plexus of lath-shaped crystals of felspar in a microcrystalline ground-mass, in which are imbedded porphyritic

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crystals of plagioclase containing numerous inclusions; augite; amygdules of quartz; and, patches and amygdules of calcite and chlorite, the latter for the most part aggregated into spherulites. Beautiful examples of cross-shaped interpenetration twins of plagioclase also occur. Abundantly scattered throughout the rock are small particles of what appears to be leucoxene, probably resulting from the decomposition of ilmenite.

Below in column I. is the result of an analysis of an unweathered sample of this rock from about 3 miles due south of Johannesburg, from the Klipriversberg. The rock selected for analysis was of the usual dark olive green colour, and contained a few calcite amygdules up to about 1 inch in greatest length; very occasional ones of quartz of rather smaller size; and numerous small, very dark green, almost black, ones, up to 0.35 inches across, which the microscope revealed to be chlorite; a small amount of pyrites, chiefly copper pyrites, was visible in places.

	I.	II.	III.	IV.
SiO_2	53.00	51.20	52.20	53.70
TiO_2	—	—	—	—
Al_2O_3	19.70	16.75	16.50	18.21
Fe_2O_3	10.93	16.87	14.50	10.64
FeO	2.88	2.88	1.20	
MnO	tr.	tr.	—	—
CaO	7.20	8.74	11.50	6.66
MgO	4.00	2.60	3.50	5.24
K_2O	0.79	0.39	0.25	0.99
Na_2O	0.82	0.50	0.28	2.65
P_2O_5	tr.	tr.	tr.	—
CO_2	tr.	tr.	—	—
FeS_2	0.25	0.018	tr.	—
H_2O	—	—	—	1.55
	99.57	99.948	99.93	99.64
Sp. Gr.	2.864	2.834		2.92

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Column II. shews the composition of the persistent sheet of amygdaloidal diabase encountered in the Upper Witwatersrand formation in deep boreholes on the far East Rand. This sheet occurs at a fairly constant horizon over a wide area in this district, and is generally considered to be a contemporaneous flow and not an intrusive sheet. It occurs some 250 feet below the Kimberley Slates, and some 2 to 12 feet above the Bird Reef series of conglomerates, and in that district is looked upon as a "marker" for this series. Approximately, it averages about 150 feet in total thickness, but is not always in one sheet, being sometimes broken up into one main sheet and several smaller bands separated by intervening quartzite. The sample is from typical pieces taken at intervals from between the depths of 3,516 feet and 3,637 feet from No. 2 borehole on the farm Grootvlei [176].

Column III. gives the analysis of a fine-grained portion of this East Rand amygdaloid, almost entirely free from amygdules, and of a light olive green colour, from the same borehole, from typical pieces, from between the depths of 3,560 and 3,606 feet.

Column IV. gives the composition of the South Dyke, High Green, near Bellingham, Northumberland. The analysis was made by Mr. Stead, of Middlesborough, and is quoted by Mr. Teall in his work entitled "British Petrography." I have inserted it for comparison, as chemically it is a somewhat similar rock.

I have paid considerable attention to the above-mentioned occurrence of amygdaloidal diabase on the far East Rand, and the conclusion at which I have arrived is that this is not a surface flow, but is an intrusive sheet. Generally speaking, it is usually considered sufficient evidence that a rock is a surface flow if it is amygaloidal. This, however, is not correct; for example, Dr.

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Corstorphine tells me that near Liversage's homestead on the farm Rietfontein, [110], in the Heidelberg district, there is a dyke of amygdaloidal diabase which is about 40 feet wide, and can be traced for about 400 yards, the direction of strike being east and west, magnetic. He describes it as a coarse amygdaloid, very like the Klipriversberg Amygdaloid in appearance, but not showing any porphyritic felspars. Moreover, there is no scientific reason why dykes and intrusive sheets should not, under certain conditions, be amygdaloidal; for, provided the temperature of the aqueous and other vapours, which have occasioned the vesicular cavities, remains above the critical temperature during the solidification of the walls of the cavities, then, no matter how great the pressure due to overlying or enclosing rock, the vapours will remain as vapours and will not liquefy, although their densities may be greatly increased, and hence these amygdule-shaped hollows will be formed, and will eventually become wholly or partially filled by the deposition of secondary silica, calcite, or other secondary mineral matter. In support of the view that this amygdaloidal sheet is intrusive, the following reasons may be adduced: In no instance do I remember it being amygdaloidal right up to the contact with the quartzites; and, I have observed that when first entered it is usually of a slaty fissile nature for the first few inches, or sometimes for even the first few feet. For example, in the Joint Grootvlei-Daggafontein borehole, amygdaloidal diabase was encountered at a depth of 4,325 feet, and was of a very slaty fissile character for about the first 7 feet, and no distinct amygdules were observed until the depth of 4,332 feet had been reached. Moreover, if a surface flow only one sheet would probably occur; or if a series of flows, the number of sheets should remain constant over a fairly considerable area; instead of which, while only one sheet occurs in both boreholes on the farm Grootvlei [176], two occur in the hole put down on the boundary between that farm and

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Palmietkuil [61], the adjoining farm on the east; the upper, 160 feet thick, ends 17 feet above the Bird Reef series, while the top of the lower one is over 77 feet below the Bird Reef series. In the No. 5 borehole on Palmietkuil no less than seven bands occur. The top one is about 210 feet thick and forms the main sheet; below this there are six smaller bands, varying from 2½ inches to 28 feet in thickness. The bottom of the main sheet is 2½ feet above the Bird Reef series, while the top of the lowest band is not only below the Bird Reef series, but is actually 18 feet below the Modderfontein series of conglomerates. Perhaps, one of the strongest proofs of this diabase being intrusive is that a small stringer of conglomerate 2½ inches thick occurs in the second band of diabase below the main sheet. This band is 28 feet thick, and the conglomerate commences two inches from the top and has diabase immediately above and below. Quite recently a borehole put down on the farm Droogefontein, which adjoins Palmietkuil on the north, has encountered this amygdaloidal diabase immediately underlying the Black Reef quartzites, clearly shewing that to reach this horizon it must have broken across the bedding of the underlying formation; and thus no doubt should now remain regarding its intrusive nature.

In the hand specimen, this rock closely resembles the Klipriversberg Amygdaloid. It varies in colour from light to dark olive green, the fine grained portions, which are almost entirely free from amygdules, being of a much lighter shade than the amygdaloidal and coarser-grained portions. The amygdules mainly consist either of calcite, quartz, or chlorite; here and there a good deal of pyrites is visible and sometimes occurs in the calcite amygdules. Under the microscope, lath-shaped crystals of felspar are clearly discernable imbedded in a fine-grained decomposed matrix; and beautiful crystals of calcite, exhibiting its characteristic polysynthetic twinning are seen infilling

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some of the amygdaloidal cavities, some of which contain both quartz and calcite. In one instance a section shewed calcite occupying the central portion, while quartz exhibiting a comb-like structure occurred as a growth around the inside edge of the amygdule, clearly illustrating how the growth had proceeded from the wall inwards. In another instance a small bleb of quartz occupied the centre, the remainder being filled with calcite. Amygdules of chlorite are also present; also, numerous amygdules of some isotropic material, which is black in the hand specimen, and is probably glass. Both in the hand specimen and under the microscope, these latter are seen to be traversed by numerous cracks (presumably due to contraction on cooling) which are filled with calcite; and they may be seen in all stages from this until consisting entirely of calcite, pointing to the probability of the calcite in the calcite amygdules, at least in some cases, having replaced this dark isotropic material by subsequent infiltration, which commenced along cracks. The microscopical features of this rock have also been briefly described by Dr. Hatch (23).

Thus macroscopically, petrologically, and chemically this rock is practically identical with the Klipriversberg Amygdaloid; and, I think, there can be little doubt that the two rocks originally formed portions of one and the same magma; and that this East Rand amygdaloid is an intrusive sheet in the Upper Witwatersrand formation; and, is connected with the Klipriversberg Amygdaloid in depth.

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The Witwatersrand and Swaziland Formations.

The Upper Witwatersrand formation covers an area in the Southern Transvaal of approximately 640 square miles; and the Lower Witwatersrand formation, or Hospital Hill series, about 970 square miles. Thus, in this portion of the country, these two formations, which may be styled collectively The Witwatersrand beds, extend over some 1,600 square miles. They are also developed to a small extent in certain parts of the north of the Orange River Colony. Dr. Hatch (18) estimates the thickness of the Hospital Hill series at 8,000 to 10,000 feet; and, that of the Upper Witwatersrand strata at 11,000 to 15,000 feet. Dr. Molengraaff (56) gives the thickness of the former at Johannesburg as about 5,900 feet. De Launay (45) estimates the thickness of the latter at about 25,000 feet. These beds have their greatest and most typical development on the Witwatersrand, from which fact they have derived their name; and the alternative name of Hospital Hill series was given to the lower formation on account of the conspicuous development of its upper beds, especially the green quartzite and magnetic slate, on the hill at Johannesburg, immediately north of the town, on which the Hospital stands, and which is locally known as Hospital Hill. These two formations are conformable; the division is purely an arbitrary one, and for convenience is placed at the base of those conglomerates known as the Main Reef series. Along the Witwatersrand the strike of these beds is east and west, and their outcrop extends from the farm Randfontein, south-west of Krugersdorp on the far West Rand, to the farms Klipfontein and Cloverfield on the far East Rand, a distance of over 40 miles. The town of Johannesburg is situated almost exactly half-way between these limits. Beyond this on the west it is covered by

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the Black Reef and Dolomite formations, with the exception of a fairly large inlier of Lower Witwatersrand strata a few miles to the west of Randfontein; and on the east it likewise becomes covered up by the Black Reef series and Dolomite. Just east of Boksburg a portion of the Upper series is covered by an outlying patch of Coal-Measures, from which it emerges some few miles further east on the farm Benoni.

The scenic aspect of the two Witwatersrand formations is diversified by alternations of low hills and valleys, with few trees, little water and scanty vegetation. The quartzites form the hills, which are characterised by their well-defined dip slopes and their steep escarpments. The slates and diabase intrusions are usually found in the valleys. Of these the diabase valleys are the more fertile owing to their greater richness in alkalies and alkaline earths. Where the dip of the beds is steep, as on the Witwatersrand, this adversely affects vegetation. At Rio Tinto, in the south of Spain, I have noticed that this latter cause affected the growth of vegetation in a very marked degree. Here palaeozoic schists and slates, pierced here and there by igneous intrusions, cover wide tracts of country. The slates and schists are either vertical or dip at a very steep angle, and little or no vegetation will flourish on their upturned edges.

These formations are older than the Ventersdorp series, by which they are overlaid unconformably. Whether they are older or younger than the Old, or Basement, Granite (so-called to distinguish it from the newer Red, or Bushveld, Granite) may, perhaps, still be considered an open question, although the weight of opinion of Transvaal geologists is in support of the Witwatersrand beds being younger (41; 27; 1; 37 and 6); but Dr. Molengraaff (57) does not acknowledge this, and considers that sufficient evidence has not yet been advanced for the final acceptance of either theory. Quite recently much light has been

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thrown on this subject, and two valuable papers have lately been read, one by Dr. Hatch (28), entitled "The Oldest Sedimentary Rocks of the Transvaal," and the other by Mr. E. Jorissen (42), entitled "Notes on some Intrusive Granites in the Transvaal, the O.R.C. and in Swaziland."

In the former paper, the Old Granite is described as being intrusive in a series of sedimentary schistose rocks at Mont Maré, to the south of Pietersburg, in certain of which such contact minerals as ottrelite and andalusite are developed. The author calls these beds "the oldest known sediments of the country;—rocks older than the Witwatersrand series, since the latter rest unconformably on the granite"; and also gives it as his opinion that "this older sedimentary series is abundantly represented in the Transvaal,—that it is in fact the great series of schistose sediments, of which the rolling uplands of Swaziland and the rugged hills of the Moodies and Sheba ranges at Barberton, as well as the hilly country near Marabastad, are composed." He proposes that this series of rocks should be called the Swaziland beds.

In the latter paper the author describes the Old Granite as intrusive into certain schists, slates, and quartzites at the following places:—(1) The farms Abelskop and Goudplaats near Schweizer Reneke, near the south-western border of the Transvaal; (2) The farm Nooitgedacht [565], Pretoria, in the centre of the Transvaal; (3) Two farms in the Vredefort District, O.R.C.; (4) The farm Malikskraal [406], Lydenburg; (5) Near Embabaan, Swaziland, about 12 miles beyond the eastern border of the Transvaal; and, (6) The Forbes' Reef Concession, south of the Komati River.

He describes these rocks as being older than the Witwatersrand series; and expresses the opinion that

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the Old Granite "is intrusive only into crystalline and metamorphic schists, remnants of an Archaean era. These preceded and were separated from the deposition of the Witwatersrand series by a lengthy period of denudation, because the mountains by then were already reduced to a 'peneplain' before the deposition of the Witwatersrand beds."

Therefore, as far as can be judged from the present state of our knowledge, it would seem that the old granite is intrusive into certain Archaean rocks consisting of slates, quartzites, and schists, but principally the latter, which may be conveniently termed the Swaziland series; and that there is an unconformity between this series and the overlying Witwatersrand beds. The latter were probably derived both from the Old Granite and from the destruction and the denudation of the rocks of this Swaziland series (27 and 41), which, undoubtedly, was of much greater extent and thickness than it is now.

Although the rocks of this Swaziland series do not outcrop between the granite and the Lower Witwatersrand formation round the edge of the Witwatersrand syncline, unless the schists to the north of the Rietfontein Mine represent a portion of this series (*), yet it is quite possible that they do actually occur, underlying the Lower Witwatersrand formation, throughout either the whole, or a portion of, this area; but they are not shewn in the section at the end of this book.

(*) Dr. Corstorphine terms these "talcose schists," and states that they are obviously unconformable beneath the Witwatersrand Quartzites. He considers them differentiations and variations in, and belonging to, the granite (G.S. Corstorphine, "The Geological Relation of the Old Granite to the Witwatersrand Series." Trans. Geol. Soc. S.A., Vol. VII, part I, pp. 9 to 12). Dr. Molengraaff on the other hand maintains that these schists are of sedimentary origin, as they very often contain conglomerates; and that the microscope reveals their sedimentary character. He thinks there are strong arguments in favour of the old granite being intrusive into these sericitic schists, and does not admit that they are unconformable below the Orange Grove Quartzite (G. A. F. Molengraaff, Proc. Geol. Soc., S.A., to accompany Vol. VIII. of the Transactions, pp. 31 and 32.)

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Gold has been found and worked in this formation in several localities, as for example in the Zoutpansberg and at Barberton. Recently very promising discoveries have been made, and much development work is now in progress, some few miles to the south-east of Schweizer Reneke in the Bloemhof district.

Unconformably overlying the Swaziland series is the Lower Witwatersrand formation which is characterised by frequent alterations of quartzites and slates, and the absence of conglomerates, while the Upper formation is remarkably free from slates, and contains numerous conglomerates. The quartzites of the former are frequently chloritic and are more compact and more crystalline, and contain less sericite than those of the latter. In the Upper Witwatersrand formation the quartzites contain much sericite, and frequently talc. Speaking generally, they are not so compact and are less often crystalline than those of the Lower formation, being frequently inclined to a talcose, schistose, nature. These differences in the Upper and Lower formations of the Witwatersrand beds are somewhat curious, especially when we remember that they are conformable. Possibly, the explanation may be that the lower beds have been principally derived from the denudation and transportation of what we have termed the Swaziland series, (†) the schists of which would have formed excellent material for the building up of the numerous slates occurring in them; while the Upper formation may have been derived, to a larger extent, from the old granite as well (‡) for doubtless by that time it would, owing to the denudation of the overlying beds, be exposed over a far greater area. The pebbles in the conglomerates

(†) The denudation of the schists and granite met with still further north, beyond the northern limits of the Transvaal, in Mashonaland and Matabeleland, has also doubtless furnished material for the building up of the Witwatersrand beds. Possibly, later work may show that these can be correlated with the Swaziland series and Old Granite of the Transvaal.

(‡) Granite is easily disintegrated in moving water, and all its constituents, with the exception of the quartz, are readily decomposed.

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mostly consist of quartz, which may have been, to some extent, derived from quartz veins in the older series and in the granite, but probably, owe their origin, mainly, to the granite and the numerous pegmatite veins which it contains.

Dr. Molengraaff (58) has already called attention to the fact that all the rocks,—conglomerates, sandstones, and shales,—of the Upper Witwatersrand formation, are distinguished by the presence of sericite. Sericite and muscovite also occur in the lower series, but to a less extent. The brown spots in the "speckled bed" of the lower or Hospital Hill series are described by the same authority (56) as due to the precipitation of hydroxide of iron in small cavities once filled by fragments of felspar, now kaolinised and partly removed. If any of these beds have been derived from the granite, we should expect to find in them a large proportion of sericite as a decomposition product of the orthoclase felspar, together with certain amounts of other decomposition products. In this connection Dr. J. A. Leo Henderson's (34) description of some auriferous conglomerate from the Angelo Mine, East Rand, is of considerable interest. He states that "The conglomerate of the Main Reef contains numerous dark-coloured pebbles besides the usual colourless or bluish quartz. Under the microscope these dark pebbles are seen to be fine-grained quartzite, impregnated with secondary dust-like pyrites, generally along fissures in the pebbles caused by cataclastic action. The gold, as usual, cannot be observed in a free state, but takes part in the composition of the pyrites. Grains of a pink-coloured corundum, needless of tourmaline and zircon, biotite leaves, and colourless to pale-green amphibole lie amongst the pyrites, muscovite, and chloritic substance between the pebbles. In the South Reef no dark impregnated quartzite pebbles were seen, but a good deal of green hornblende twinned $\| \infty P \infty$ (100), and

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many grains of pink corundum, with well-formed crystals of zircon, are present." The quartzite pebbles may have been derived from the Swaziland series. The presence of tourmaline, zircons, corundum, chloritic material, colourless to pale-green amphibole, green hornblende, muscovite and biotite certainly suggest that the matrix of the conglomerate was derived from the Old Granite.

I do not propose to describe the Witwatersrand beds in detail, as this has already been done by others (‡), but intend merely to confine my attention to some of their most interesting and characteristic features. To those who wish to make a closer study of this subject I would recommend the works mentioned in the footnote to this page.

In the Hospital Hill series certain characteristic beds occur, which are very useful as "markers" and have been frequently used as such for approximately locating the horizon of the Main Reef series, especially as the beds of the upper formation are far less easily recognisable as belonging to a definite horizon, with the exception of the conglomerates, and even with them it is often difficult to at once determine the particular banket series to which they belong. Of these characteristic beds the chief are, enumerating them from below upwards:—The Orange

(‡) Dr. Molengraaff. "Geology of the Transvaal," pp. 4 to 18 (for a general description).

Dr. Molengraaff. "Note on the Geology of a Portion of the Klerksdorp District, with Special Reference to the Development of the Lower Witwatersrand Beds and the Vaal River system." Trans. Geol. Soc., S.A., Vol. VIII, pp. 16 to 25.

Drs. Hatch and Corstorphine. "The Geology of the Bezuidenhout Valley and the District East of Johannesburg." Trans. Geol. Soc., S.A. Vol. VII, part II, pp. 97 to 109.

Drs. Hatch and Corstorphine. "The Petrography of the Witwatersrand Conglomerates with Special Reference to the origin of the gold." Trans. Geol. Soc., S.A., Vol. VII, part III, pp. 140 to 145.

Hatch and Chalmers. "The Gold Mines of the Rand." (Macmillan and Co., 1895).

S. J. Truscott. "The Witwatersrand Goldfields." (Macmillan and Co., 1902).

M. L. de Launay. "Les Mines d'Or du Transvaal." (Annales des Mines. 9, IX. Paris, 1896).

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Grove Quartzite; the Ripple-marked Quartzite; the Speckled Bed; the Hospital Hill Slate; the Green Quartzite; and the Red Bar. The first and the three last are the best known; and of these the Red Bar was considered of far greater importance in the early prospecting days of the Rand than it is now. The Hospital Hill Slate and the Green Quartzite have attracted a great deal of attention, especially of late. It has been contended that the Green Quartzite should not be used as a marker, and that its name is not a good one, as the colour of a rock need not be an essential feature, and is liable to vary. However, in this particular instance, the colour is so constant over big areas and in widely separated districts that, I think, especially when this bed is considered in conjunction with other leading beds, one is certainly justified in looking upon it as a "marker." This quartzite can be seen well exposed at the side of the road in Twist Street, and also by Braamfontein Church, both on Hospital Hill. The bed of Hospital Hill Slate is undoubtedly the most characteristic feature of the whole of the Lower Witwatersrand formation. It is well exposed on the ridge of Hospital Hill, just north of Barnato Park in Joel Road; in the cutting made for the electric tramway through this ridge in Tudhope Avenue; and, also at the Show Ground, Braamfontein.

About two years ago, a storm of controversy was aroused, owing to the theory having been advanced by one of the leading mining engineers of the Rand (4) that this rock, and also the footwall slate of the Main Reef and the slate occurring between the Kimberley and Bird Reef series of conglomerates, were not slates, and were, in fact, not sedimentary, but igneous rocks. One good which resulted from the discussion was that these rocks were proved, beyond all question, to be of aqueous origin; and it was shown that they might be appropriately termed quarzitic slates. Previously, this had been the generally accepted

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opinion, about which few had considered there were grounds for controversy. Dr. Hatch (24), who took part in the discussion, in describing the two latter rocks, from sections from the eastern portion of the Witwatersrand which he had examined under the microscope, writes: "The slates, both in point of composition and structure, are closely related to the quartzites with which they are associated. We find that both quartzites and slates are composed of angular to sub-angular fragments of quartz imbedded in a micro-crystalline ground-mass. There are occasional flakes of a yellowish-green pleochroic mica, and iron pyrites occur abundantly as an accessory constituent. Where the slates have a greenish tinge this is due to the abundant presence of chlorite. The ground-mass is too minutely granular to allow of specific minerals being recognised, but it reacts under polarised light, and probably consists mainly of very finely comminuted quartz, together with a micaceous mineral, either muscovite or sericite, in minute blades. It is possible that there is also some admixture of clayey matter, kaolin or some similar mineral. . . . . The differences observable under the microscope between quartzite and slate consist, firstly, in the size of the quartz grains, and, secondly, in the relative proportion of quartz grains and matrix in the two rocks. In the quartzite the quartz grains are fairly large and the ground-mass subordinate; in the slate, on the other hand, the quartz grains are small to minute and the matrix predominant. The difference might be compared to that existing between sands and slimes when speaking of tailings. Where a banded structure is observable in a hand specimen of slate, under the microscope this is seen to be due solely to minute variations in texture and relative proportion of quartz grains, such as might be expected to occur under conditions of sedimentation from currents. . . . . In short, the rocks I have examined are not igneous, but of detrital origin, or, in other words, they are true sediments

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of a quartzitic nature, and are correctly to be designated as slates on account of their minutely comminuted character, their banded or zonal variation due to sedimentation, and their slaty cleavage, which is, of course, a superimposed structure due to pressure and may or may not be coincident with the bedding planes."

Later, in another paper contributed to this discussion, (26) he writes, (referring to these same slates): "These slates are banded, not only at the surface, but in depth also as far as the deepest boreholes have intersected them, and microscopic examination shews them to be composed mainly of minute quartz granules. To my mind, and I think I am supported in this by every petrologist on these fields who has examined them, these rocks are true sediments. They can be seen passing by minute gradations into true quartzites, and furthermore narrow slate bands are found alternating with sandy or quartzitic bands. The same applies to the Hospital Hill Slates, which shew the most beautiful ribbon banding in cores derived from deep boreholes (1,100 feet at Holspruit, and in the Geldenhuis Estate), and I have not the slightest doubt that these too are of sedimentary origin. Microscopic examination of these rocks is rendered more difficult than in the case of the other slates, owing to the quantity of magnetic iron ore they contain, but sections can be obtained shewing that they are largely made up of fragmental quartz." So much for the microscopical features of these slates. As regards the chemical composition of the Hospital Hill Slate, Mr. George Denny (5) gives the following (Col. I.) as the average of ten analyses, but does not state whence his samples were obtained. I assume that they are from outcrops; and, the amount of water present in the rock shows that it could not have been very fresh. The other two analyses shew the results obtained by Mr. H. F. Marriott (47) from samples of this

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slate obtained from the cutting at the entrance to the Show Ground, Braamfontein. Col. II. represents the composition of a fair average sample taken at intervals of 3 feet over a total distance of 225 feet across the formation; and, Col. III. that of an average section of the typical banded and crumpled portion of the series taken over a distance of 48 inches in width, on the eastern face of the cutting, just inside the gate :—

	I.	II.	III.
SiO_2	54.48	53.36 } 90.80	51.56 } 99.04
Fe_2O_3	25.38	37.44	47.48
FeO	—	0.09	0.90
Al_2O_3	12.11	5.96	tr.
CaO	0.40	none	none
MgO	0.95	do.	do.
Na_2O } K_2O }	1.36	not est.	not est.
H_2O	5.00	do.	do.
TiO_2	0.51	do.	do.
S	—	do.	do.
	100.19	96.85	99.94

As Dr. Hatch (29) pointed out at the time, lime and magnesia are absent in Mr. Marriott's analyses, and the amounts of the alkalies, although undetermined, cannot be great; the bases, therefore, necessary for the presence of the ferro-magnesian minerals, characteristic of basic igneous rocks, are almost entirely absent; also, if the results be compared with acid igneous rocks, they are found to be deficient in alumina and alkalies.

The Hospital Hill slate may be described as a banded, magnetic, ferruginous quartzitic slate, varying in colour from reddish-brown to black.

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Below in Col. I. is given the result of an analysis, which I have recently had made, of the Van Ryn footwall slate from No. 1 borehole on the farm Grootvlei [176] on the far East Rand. The sample is from between the depths of 3,421 feet and 3,431 feet. Here it is a dark green rock, having a black satiny lustre on a cleavage surface. In the hand specimen the banding appears to be due to alternations of fine grained with coarser and more quartzitic portions, the latter being lighter in colour than the former. It rapidly weathers to a dirty yellowish-green colour on the exposed longitudinal core surface, and is dull black on the surface of a transverse section at right angles to the length of the core.

	I.	II.
SiO_2	56.78	58.45
TiO_2	—	—
Al_2O_3	15.96	16.86
Fe_2O_3	13.56	10.69
FeO	5.94	—
CaO	0.98	tr.
MgO	4.45	2.50
K_2O	0.78	0.99
Na_2O	1.30	1.40
FeS_2	tr.	0.658
Loss on ig.	—	8.08
	99.75	99.628
Sp. Gr.	2.816	2.783

Col. II. shews the composition of a typical sample of the Kimberley banded slate, which I have had analysed. This is the slate occurring between the Kimberley and Bird Reef series of conglomerates on the far East Rand. The sample was obtained from No. 1 borehole on the farm Grootvlei [176] at intervals between the depths of 3,050 feet and 3,170 feet. The banding was well marked,

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and was apparently mainly due to difference in grain. The portions producing the banding were of a greyish-white colour, and had the appearance of a very fine-grained quartzite. The colour of the rock, as a whole, was greyish-blue on the exposed longitudinal surface of the core ; it presented a black satiny lustre on a cleavage surface, and was dull black on a transverse surface at right angles to the length of the core. The rock was traversed, more or less parallel to the bedding, by frequent minute veinlets of calcite.

In boring for the Main Reef, it is often a difficult matter to correctly decide whether certain slate bands encountered belong to the Kimberley or the "footwall" slates; and the question at issue is whether the slate is above or below the Main Reef horizon ; and, consequently, whether the hole should be continued or abandoned. Thus the importance of the difference in chemical composition of these two rocks, especially if future work should prove that this is constant over wide areas, can hardly be over-estimated. This is the more important because it has been found that this question cannot definitely be settled by the examination of thin sections under the microscope. Dr. Hatch (25) first called attention to the presence of rutile in the Kimberley slates, and described it as occurring in innumerable minute hair-like needles or spicules, characterised by high refractive index, straight extinction under crossed nicols, and the occasional presence of knee-and-heart-shaped twins. Since then, rutile has also been found to occur in the "footwall" slates, so that it is not a distinguishing feature confined to only one of these two slate horizons. The rutile must be present in very minute quantity compared with the bulk of the rock, since both rocks were tested for titanium, by the usual methods employed in rock analyses, and in neither case could even a trace of this element be detected.

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With regard to the conglomerates: in the Lower Witwatersrand formation only one series of any great importance occurs, and this is not continuous over long distances. The only place where it is successfully worked is at the amalgamated Rietfontein Mines, about four miles north-east of Germiston. These conglomerates are known as the Du Preez series. The youngest series of conglomerates occur at the top of the Upper Witwatersrand formation and are known as the Elsburg series. Some (9 & 32) think an unconformity exists at the base of this series; and, it has been suggested by Dr. Hatch (30) that the Du Preez series may, perhaps, be an outlier of unconformable Elsburg conglomerates. If this be so, a portion of the Elsburg series must have been, so to speak, sandwiched in between strata of the Lower Witwatersrand formation as a consequence of complicated faulting and earth movements, such as we know have taken place in that locality, the results of which are especially evident in the present geology of the Bezuidenhout Valley. Quite recently, a northern series of conglomerates, occuring in this formation, called the North Rand series has received a certain amount of attention; and, development work on it is in progress. Whether this series can, or cannot, be correlated with the Du Preez series, several miles further east, remains to be seen when more work has been done. Other conglomerates, known as the Dominion Reef series, in the Klerksdorp district, which were worked for gold at the former Dominion Mine as early as the year 1889, have also recently attracted some attention; and, were lately described in considerable detail by Dr. Molengraaff (69), who speaks of the conglomerates as occurring in the lowermost portion of the Lower Witwatersrand beds and the lowest reef of the series as always resting on a fine-grained white sericitic schist. There is also, in another part of the same district, a reef

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occurring in the Lower Witwatersrand formation on which the Elandslaagte Gold Mine is at present working.

In the Upper Witwatersrand formation five principal series occur. Enumerating them, from below upwards, they are the Main Reef, Livingstone, Bird, Kimberley and Elsburg series. For a detailed general description of these I would refer the reader to the works previously mentioned by Hatch and Chalmers, Truscott, and De Launay.

As already mentioned, it has been suggested that an unconformity may exist at the base of the Elsburg Series (32) and that possibly this series belongs to the Ventersdorp beds, and should not be grouped with the Upper Witwatersrand formation. If there is unconformity, it seems to me that it would be better to treat the Elsburg series as a separate formation than to treat it as the lowest member of the Ventersdorp series; as the latter is essentially a volcanic series. One of the strongest arguments brought forward in support of the theory that an unconformity exists is, that fragments of Lower Witwatersrand beds occur in the Elsburg series. I have certainly seen pebbles of slate which greatly resemble Hospital Hill slate in this series; and numerous quartzite pebbles also occur; but, it is quite possible that these were derived from the Swaziland series.

On the far East Rand, the Elsburg series together with the overlying Klipriversberg Amygdaloidal Diabase are missing. Probably the latter is represented by the sheets of amygdaloidal diabase encountered in the Witwatersrand beds (in both Upper and Lower formations) in this district. The Kimberley is here the best developed of the four remaining series. In the joint Grootvlei-Daggafontein borehole, where it was more than

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usually well developed, no less than 136 leaders and beds of conglomerate were encountered, having an aggregate thickness of over 170 feet, and extending over a depth of 1,492 feet, between the depths of 2,000 feet and 3,492 feet (‡). They varied in thickness from half an inch up to 28 feet 11.5 inches. There were:—

69 under 6 inches thick.
29 of 6 inches and over, up to 1 foot.
20 of 1 foot and over, up to 2 feet.
7 of 2 feet and over, up to 3 feet.
11 of 3 feet and over, including three unusually large beds, 14 feet 10 inches, 28 feet 11.5 inches and 9 feet 7 inches respectively.

136 = Total number of bands of conglomerate.

The Bird, and the Modderfontein (Livingstone series of the Central Rand) series are, here, only poorly developed; and, usually consist of one or two reefs, varying in thickness from rather less than a foot to over 2 feet, and some 3 or 4 up to a dozen, or occasionally more, small leaders and stringers, the total aggregate thickness of conglomerate for either series only averaging about 3 or 4 feet.

The Main Reef series, or Van Ryn Reef series as it is termed in this district, is also poorly developed, and varies in thickness from about 4 or 5 inches up to 3 feet. It is usually accompanied by some 3 to 6, or more, leaders. The total aggregate thickness of the conglomerates is seldom more than 3 or 4 feet, and is sometimes considerably less. The reef itself almost invariably rests immediately on a slate footwall; hence the name "Van Ryn footwall slate" for this latter rock. Very occasionally, however, it is separated

(‡) The thicknesses and depths given have not been corrected for any deflection of the borehole from the vertical which may have taken place.

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from it by a few inches of quartzite. As might be expected, the assay values of the reef samples obtained by boring vary greatly. The reef core obtained is, usually, only 1⅜ inches in diameter; and, the object of boring operations is not to ascertain the value of the reef, but to find out whether the Main Reef exists in that particular locality and, if so, at what depth. The depth at which it is encountered as calculated from the length of rods employed in drilling is often misleading, being sometimes as much as several hundred feet out (‡), owing to the hole having deflected. Hence, in order to obtain the vertical depth from surface at which the reef occurs, it is necessary that the hole should be surveyed and the proper corrections applied. From numerous surveys which have recently been made it would seem that the tendency is for a borehole to deflect against the dip of the beds.

The assay results of borehole cores on the far East Rand have varied from 2 dwts in one of the Brakpan holes up to over 5 ounces in one of the Geduld boreholes. The assay plan of almost any mine on the Rand will shew equally varying results; and, although some idea of the probable value of the reef may be obtained from the results of the nearest producing mines, yet it is only by actual development work that the value of the property can be proved with any approach to accuracy.

It is somewhat difficult to give an adequate general description of the various series of conglomerates of this district; but, I have noticed that the Kimberley series is characterised by:—

1. The presence of white and also bluish quartz pebbles, rounded, sub-rounded and angular; the white

(‡) At a meeting of the Brakpan Gold Mines, held in Johannesburg on the 31st May, 1905, the Chairman, in referring to boring operations which had taken place on their property, stated "the differences in depth as indicated by drilling and determined by actual survey amounted in some instances to as much as 1,100 feet."

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quartz pebbles predominating, and occurring up to 1.75 inches, the blue ones usually only occurring up to 1 inch, in greatest thickness.

2. Being well-pebbled and pyritic, in places very pyritic; the pyrites occurring both in and immediately around the pebbles.

3. The presence of occasional angular and sub-angular striped and unstriped, also black, white or light-coloured chert pebbles up to 1.5 inches in greatest thickness. Also, by the occasional, but rare, occurrence of a rounded chert pebble.

4. The presence of a few angular and sub-angular slate (both striped and otherwise) pebbles, usually long and narrow, up to about 1 inch in greatest length.

5. The presence of occasional angular yellowish-green, light olive-green, pale grass-green or bright green talc pebbles, up to 1.25 inches in greatest thickness.

6. The very occasional presence of an angular drab-coloured pebble (which can be scratched with a knife), occurring up to 0.9 inches in greatest length.

The Bird and Modderfontein Reef series are usually not well defined, and do not contain such large pebbles as the Kimberley series does; they consist mostly of small, sub-angular, angular and rounded, white, blue or black quartz pebbles, up to about 0.5 inches in greatest thickness but occasionally occurring up to double this size. The proportion of rounded pebbles is usually less than in the Kimberley series, and the majority of angular pebbles present is often quite a noticeable feature; small angular striped and also unstriped slate pebbles, and occasional striped and also unstriped chert pebbles, up to about the same size as the quartz pebbles, occur. Some of the leaders are frequently very pyritic.

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After the Kimberley and Bird Reef series have been passed through, I have frequently noticed that minute black specks make their appearance, sparsely scattered here and there through the quartzite, especially when the quartzite assumes a white crystalline and saccharoidal character, and these continue right down to the Main Reef series, in which they also sometimes occur (†). I have also noticed that above, and in the immediate neighbourhood of, the Main Reef occasional very small azure blue pebbles, up to about ⅛th of an inch in diameter, frequently occur.

In the Van Ryn or Main Reef series the most numerous pebbles are usually of either white, blue or black quartz, rounded, sub-rounded and angular. The white are generally the larger, and occur up to about 1 inch in diameter; the blue usually do not exceed half this size; occasionally, the white quartz pebbles are found up to about 2 inches, and the blue up to nearly 1½ inches in diameter. Sometimes black, white or striped angular chert pebbles up to 1 inch in diameter also occur, and rounded green talc pebbles up to ½ inch diameter. Portions are frequently somewhat pyritic.

The chert pebbles are almost invariably more or less angular, while the quartz pebbles, especially in the Kimberley series, are characterised by being very frequently beautifully rounded. The former only slightly exceed the latter in hardness; and, therefore, if they had both travelled the same distance, one would expect to find the chert pebbles only slightly less rounded than the quartz pebbles. The inference, therefore, is that the chert have been derived from a source less remote than the quartz pebbles. The slate

(†) I have had sections cut of these, but they were too indistinct and decomposed for me to be able to determine them under the microscope.

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pebbles are invariably angular; and, as they are softer than those of chert or quartz, they, presumably, could not have travelled as far as either of the latter. Some think they are derived from the Lower Witwatersrand beds, and I have myself found pebbles in the Kimberley series much resembling the Hospital Hill slate. This would suggest that an unconformity may possibly occur between the Upper and Lower Witwatersrand formations; but, I have seen no evidence to support such a theory, and as regards these slate pebbles, it seems to me much more probable that they are derived from the Swaziland series, which we know contains slates almost identical in appearance with the Hospital Hill slate. The angular talc pebbles (unless formed *in situ* as a decomposition product) must have travelled a very short way, the hardness of talc according to Mohs' scale being unity. If the conglomerates are shore deposits § then during their deposition, at all events in the case of the Kimberley series to which these angular talc pebbles are in this district mainly confined, there can have been very little current disturbance, as the trituration produced would have been sufficient to entirely grind away any talc pebbles, and we should not to-day be able to record their presence in these conglomerates, unless they were formed *in situ* as suggested above. Some of this talc may have existed as an original constituent of talc-schists; but, probably the greater part, if not all, is an alteration product of such minerals as mica, hornblende, and perhaps also augite. This would lend support to the theory that these beds have been derived from the Swaziland series and from the Old Granite.

Although traces, and sometimes more, of gold occur in the other series of conglomerates, yet the gold is chiefly

§ And this is the general, and probably the correct, opinion, although accumulations of pebbles may occur, due to the agency of wind, as, *e.g.*, the pebble-covered plains of Arizona; and, of the northern arid regions of South Australia.

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confined to the Main Reef series, and the question naturally arises why this should be. If we accept the theory that the gold has been deposited from ascending mineralising solutions (†), which have come up along lines of weakness such as, perhaps, the junction planes between dykes and their walls; then it is easy to imagine that as these solutions ascended a point would at length be reached where it would be easier for them to circulate along the bedding than to ascend further in a more vertical direction; this position would naturally be determined by the porosity of the beds, which, other things being equal, would depend on the compression due to the superincumbent weight of strata; but, as these beds consisted of slates, quartzites and conglomerates, each of which would, under similar conditions, be more porous than the previously-named, these solutions would naturally select a conglomerate bed. The first of these, with the exception of a few in the Lower formation, including, perhaps, the Du Preez series (*) would be the Main Reef conglomerates; and the impervious footwall slate, where present, would doubtless have exerted a favourable influence by helping to retain the mineralising solution above it. Although all the conglomerates, quartzites, and slates may have been more or less permeated by the mineralising solutions, yet the main circulation of these solutions would doubtless have been confined to certain channels, such as those suggested.

(†) These solutions also no doubt contained pyrite and silica in solution as well as gold.

The reader will find a bibliography of the literature on this subject in the Proc. Geol. Soc. S.A. (to accompany Vol. VIII of the Transactions), page 28.

(*) This series is auriferous. Traces of gold can be found in every series and in much of the intervening quartzite, indicating that the whole of the Witwatersrand beds have been more or less permeated with mineralising solutions. Possibly, the carbonaceous matter present in the Du Preez series possessed some favourable influence which caused the precipitation of the gold from the solutions, or a greater amount of precipitation than might otherwise have occurred (71). While probably, the conglomerates of this lower series which do not contain gold in payable quantity did not afford so easy a channel as the Main Reef series, owing to their being smaller-pebbled, and to their compactness due to the greater weight of overlying beds.

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It is found that the average gold values of the Main Reef series for the whole of the Witwatersrand decrease slightly in depth. This is only to be expected, because, as the mineralising solutions, circulating along the bedding planes of the conglomerates, approached nearer and nearer to the outcrop the temperature and pressure would both gradually decrease, and so they would be able to retain less and less gold and pyrite in solution, and therefore more and more would be deposited; thus the outcrop would be richest, and those sections near the outcrop somewhat richer than still deeper portions. In illustration of this it is worthy of note that the average yield in fine gold per ton for the whole of the Witwatersrand, but not including outside districts, for the year 1890 was 11.626 dwts., and for 1904 it was 9.079 dwts. The average yield per annum for the six years, 1890 to 1895 inclusive, was 10.949 dwts. per ton; and for the six years, 1896 to 1904 inclusive, omitting the war years 1899, 1900, and 1901, the average yield per annum was 9.465 dwts. per ton. However, one must remember that in the early days work was chiefly confined to the Central Rand, which we now know is much richer than the eastern or western Rand, so that this partly accounts for the higher yield formerly than at present; and the lesser average yield now is, therefore, not only due to the greater proportion of deep level yields; but also to the greater proportion won from the far East and far West Rand.

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Granites.

One cannot do better than introduce this subject with the words of the late Charles Darwin (2)—"Granite to the geologist is classic ground: from its widespread limits, and its beautiful and compact texture, few rocks have been more anciently recognised. Granite has given rise, perhaps, to more discussion concerning its origin than any other formation. We generally see it constituting the fundamental rock; and, however formed, we know it is the deepest layer in the crust of this globe to which man has penetrated."

South Africa furnishes no exception to this rule: the granite of Cape Colony, which is intrusive into the Malmesbury Beds; the granite, with its accompanying schists, of Mashonaland and Matabeleland; the Old, or Basement, Granite of the Transvaal; and the Red Granite of the Transvaal Bushveld are indeed classic ground; and they cover vast areas. Possibly, later work will shew that the two first-mentioned granites may be correlated with the Basement Granite of the Transvaal. In the Southern Transvaal, the Basement Granite and old crystalline rocks extend over about 1,300 square miles of country. The Red, or Bushveld Granite, with eleolite-syenite and allied rocks, with the exception, perhaps, of certain intrusive sheets to be mentioned later, do not occur in the Southern Transvaal, but occupy some 13,000 square miles to the north, in that portion of the Transvaal known as the Bushveld.

As regards the scenic aspect of the granite country, that occupied by the Old Granite may be described as gently undulating and fertile; but, usually only sparingly

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wooded. The area covered by the Plutonic series of the Bushveld is also undulating, but is more diversified, is fertile, and is characterised by the growth of low scrub and thorn bushes; but, not by large timber.

Microscopically, the Old Granite varies very considerably; but, that occurring at Orange Grove, about three miles north-east of Johannesburg, may, I think, be taken as typical. This is a dark grey rock, characterised in the hand-specimen by large porphyritic crystals of plagioclase and orthoclase felspar, frequently corroded, measuring up to about 1½ inches in length by about half an inch in width; by rounded blebs of quartz, a quarter of an inch or more in diameter; and, by the abundant presence of small particles of a dark green ferro-magnesian mineral scattered throughout the mass, and sometimes occurring in the felspar, and imparting a distinctly dark shade to the rock as a whole. From several sections which I have examined under the microscope, I find this rock is made up of the following:—orthoclase and plagioclase felspar, turbid and cloudy through kaolinisation; abundant microline, mostly water-clear, the characteristic cross-hatching and spindle-shaped structure of the lamellæ being especially well-marked; quartz; fibrous green hornblende; a little light green mica (biotite); abundant small crystals of sphene; and, a small amount of chlorite. Here and there, small patches occur shewing good granophyric structure of the quartz and felspar; indicating, where present, that these two constituents have crystallised simultaneously from the original magma. The quartz exhibits undulatory extinction, suggesting that, here, the granite has been subjected to considerable pressure. This Orange Grove Granite may therefore be termed a hornblende-biotite-granite.

This occurrence is noteworthy since Mr. J. J. Harris Teall in his work entitled "British Petrography" has

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pointed out that microcline, while common amongst granites with two micas, is rare in the biotite- and hornblende-granites.

As Dr. Molengraaff (64) has observed the Old Granite may also occur as biotite granite, more rarely a granite with two micas, and occasionally a granite with muscovite. This author has given such a very careful and detailed petrographical description of the Old Granite occurring in the Klerksdorp district that I cannot do better than quote it in full. After describing it as a grey granite of medium grain, of which the lamellar twinned character of the triclinic felspar is easily recognisable with a pocket lens, he writes as follows (70) :—" Under the microscope the rock shows a typical granitic hypidiomorphic structure. The primary constituents are microcline, plagioclase, orthoclase, quartz, muscovite, some iron ore, biotite, rutile, zircon and tourmaline. The secondary constituents are chlorite and muscovite. Felspar and quartz preponderate so much over the other minerals that the latter only occur in clusters here and there in the rock, or as enclosures in the quartz or felspar. Iron ore is very sparingly represented by some crystals of magnetite and by some hydrated iron oxide, which may have been derived from haematite. Mica is chiefly represented by muscovite; part of the muscovite is altered into chlorite in such a way that each crystal of muscovite is altered into a chlorite crystal with the same crystallographic orientation. The chlorite is distinctly pleochroic, and shows 'Höfe' with very strongly marked pleochroism, and those often contain in their centres minute grains of zircon. The muscovite enclosed in quartz is always quite undecomposed. Biotite occurs only in small quantities enclosed in quartz or in felspar. Felspar occurs chiefly as microcline, which forms, in fact, the bulk of the rock. With the exception of quartz the microcline was the last mineral to crystallise

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in the rock, which is proved by the fact that numerous well planed crystals of orthoclase—mostly Carlsbad twins—and also crystals of plagioclase are enveloped by microcline. The characteristic 'Gitterstructur' of the twinning is very fine. The microcline was found to be quite fresh and undecomposed in all the specimens, whereas both orthoclase and plagioclase were less pellucid and partly decomposed, numerous small flakes of secondary muscovite having been formed in them. Quartz fills the gaps left after the crystallisation of all the other minerals, and also contains all these as enclosures; zircon, rutile and tourmaline are found only as enclosures in the quartz. The rock shows signs of having been subjected to great pressure, which is revealed under the microscope by the undulatory extinction of the quartz, and by the numerous bends and cracks in the other minerals; this last phenomenon is, of course, most clearly shown in the lamellar plagioclase."

Generally speaking, the Old Granite is of a grey colour; and, is usually characterised by the presence of microcline, which has, up to the present, not been found in the Red Bushveld Granite. Occasionally pink varieties of this granite are met with as, for example, near the Yokeskey River on the farms Rietfontein [15] and Driefontein [461], both situated in the central portion of the big granite boss between Johannesburg and Pretoria. The Yokeskey River granite has been described by Dr. J. A. Leo Henderson (35), who calls attention to the undulose extinction of the quartz and felspars; bent and broken felspars; broken needles of rutile in the quartz grains; and, contorted mica folia; all indicating that considerable catalastic action has taken place. From sections which I have examined of this rock from the above farms I find that the felspar element is represented by microcline and plagioclase; the former is the more abundant of the two, and much of it is water-clear.

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Other minerals present are quartz, exhibiting undulatory extinction; biotite, which is very plentiful and frequently occurs in broken flakes; chlorite, resulting from the decomposition of the biotite; and, a very small amount of muscovite. The rock certainly shows signs of considerable cataclastic action. One section, from the granite on the farm Driefontein [461], showed this in a very marked degree. Good granophyric structure of the quartz and felspar may be observed in places. Dr. Molengraaff (59) mentions the occurrence of Old Granite, of a red colour, in the Vredefort granite mass, and in some localities of the Vryheid district. Quite recently a pink variety of graphic granite was encountered, 50 feet from the surface, in sinking a well near the south-west corner of the township of Illovo, about 5 miles north of Johannesburg. I have examined this, in section under the microscope, and find it consists entirely of a beautiful intergrowth of quartz and of water-clear microcline; the granophyric structure indicating simultaneous crystallisation of the two minerals. Presumably, it occurs as a pegmatite vein in the Old Granite.

The Old Granite contains numerous veins of pegmatite and also of quartz, and is pierced here and there by dykes of diabase.

The newer Red Granite differs very considerably from the Old Granite. The former is characterised macroscopically by its persistent pink colour, due to the presence of an abundance of red crystals of orthoclase and anorthoclase felspars, which seem to be the predominant minerals. Quartz, generally in rounded blebs or more or less granular; biotite; and, sometimes, an amphibole mineral are also easily distinguishable. From sections which I have examined, I find it contains orthoclase, some plagioclase, quartz,

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biotite, hornblende, and, sometimes, muscovite. Granophyric structure is so frequently and beautifully exhibited that it is as much a characteristic feature of the typical Red Granite as the presence of microcline is in the case of the Old Granite. Occasionally microperthite, consisting of orthoclase with included streaks and lamellæ of plagioclase, also occurs.

A very interesting isolated patch of this Red Granite occurs on the edge of the Bushveld country at Balmoral, some 50 miles to the east of Pretoria, on the Delagoa Bay Railway. The granite of this locality differs slightly from the typical granite of the Bushveld. Coarsely crystalline in texture and of a salmon-pink colour, it is chiefly composed of pink felspar and quartz, the former predominating. In addition, but subordinate, are numerous light yellowish-green patches of a ferro-magnesian mineral, much decomposed. Under the microscope it is seen to consist of a holocrystalline aggregate of fresh plagioclase felspar; microperthite, consisting of orthoclase with included streaks of plagioclase; quartz; a pale green, much decomposed, ferro-magnesian mineral; and, patches and individual grains of fluorite, determined mainly by its violet colour and by being singly refracting. The chief interests attaching to this granite mass are the number of variations in the granite, occurring within a very small area—about one square mile—along its eastern marginal portion; and, the presence of mineral veins containing nickel and cobalt, and others yielding galena, in the immediate neighbourhood; which could hardly fail to suggest, to even a casual observer, that the common source of the minerals and ores has been the eruptive magma which yielded the adjacent granite mass, together with the vapours and mineralising solutions that have so greatly affected its marginal portions. In another place (38), I have already described these variations in some detail, so I will, now, only

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briefly describe the two most pronounced types. One of these is a quartzose rock, which might easily be mistaken in the hand specimen for a dense white quartzite; but which, from its microscopical features and its field relations, is undoubtedly of igneous origin and a portion of the granitic mass. The other is a rock intermediate between the latter and the typical coarse-grained granite; it is a true greisen (‡), and has doubtless originated from the granite, owing to the alteration of a portion of the latter by pneumatolytic processes. In the hand specimen, it is light yellowish-grey in colour, and is seen to consist of quartz and small grains of yellow mica, the former predominating; also, here and there are remnants of a decomposed mineral, which has a pink tinge, and is presumably felspar. In section under the microscope, it is seen to consist of a holocrystalline aggregate of quartz and scattered fibrous bunches of pale yellowish-green mica. Topaz appears to be absent, which is somewhat remarkable, as it is so generally present in greisens, especially in the locality of mineral veins.

Below are the results of some granite analyses I have had made:—

Col. I.—Orange Grove Granite (fresh; blasted for building purposes.)

Col. II.—Balmoral Granite (moderately fresh; from a shallow pit on the extreme S.W. portion of the farm Eenzaamheid).

Col. III.—Bushveld Granite (fresh; blasted from a large boulder about quarter of a mile south of the Albert Silver Mine, on the farm Roodepoortje [149]).

(‡) Incidentally, I believe, I was the first to mention the occurrence of greisen in the Transvaal. *Vide* Trans. Geol. Soc. S.A., Vol. VII, part II, page 111.

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	I.	II.	III.
SiO_2	78.61	80.00	75.84
TiO_2	—	—	—
Al_2O_3	7.76	10.87	11.14
Fe_2O_3	4.51	2.57	4.68
FeO	1.69	tr.	0.01
MnO	—	tr.	tr.
CaO	2.60	1.05	1.04
MgO	0.90	0.79	0.27
K_2O	1.74	2.05	3.92
Na_2O	2.10	2.51	2.69
P_2O_5	tr.	tr.	tr.
CO_2	...	...	tr.
B	—	—	—
Fl	—	tr.	—
Li	...	...	tr.
S	—	—	—
Moisture	—	—	0.02
Loss on ig.	—	—	0.64
	99.91	99.84	100.25
Sp. Gr.	2.712	2.599	2.626

These results are very interesting. It will be noticed that the differences between the results of Col. I. and Col. II. are slightly less pronounced than those between those of Col. I. and Col. III., with the exception of the iron; and the higher proportion of silica and lower proportion of iron, alumina and alkalies in the Balmoral Granite, as compared with the Bushveld granite, is doubtless due to alteration and weathering of the former.

Comparing Cols. I. and III. one notices that in the latter the proportion of alumina is greater; that of lime and of magnesia less; while not only are the amounts of the potash and soda more; but, that of

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the former is greater than that of the latter, due, doubtless, to the greater proportion of orthoclase in the Bushveld granite as compared with that in the Old Granite. The less amounts of magnesia and lime in Column III. indicate a decrease in the proportions of ferro-magnesian minerals and plagioclase respectively.

In the case of the Orange Grove granite, the microscopical examination has been more searching than the chemical; from the former there can be no doubt about the presence of sphene; yet the titanium was in too minute quantity to be detected by the ordinary methods of rock analysis. The chemical confirms the microscopical examination with regard to the presence of fluorspar in the Balmoral granite. The presence of traces of lithium in the Bushveld granite indicates that lithia-mica, in minute quantities, occurs in this rock.

With regard to the relative age of these granites; the Old Granite is apparently, according to the present state of our knowledge, older than the Lower Witwatersrand formation, but younger than the Swaziland beds. The Red Bushveld granite occupies a fairly constant horizon between the Pretoria and Waterberg formations. That it is younger than the former, there can be no doubt. Mr. E. T. Mellor (48) claims to have proved that, at all events, the Balmoral mass is intrusive into, and therefore younger than, the Waterberg formation; and, he says "There can be little doubt that the Balmoral intrusion is connected in origin with the main mass of the Red Granite occurring further north." He describes this occurrence as a laccolitic intrusion below the Waterberg series; and states that the upper surface of the granite intrusion, while following in general the bedding of the overlying Waterberg rocks, frequently breaks across from one bed to another; and, also that the shales are everywhere baked, altered, brecciated, and frequently penetrated

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by intrusive veins of granitic material. My study of this occurrence of granite (39) certainly led me to the conclusion that, here, the granite was younger than the Waterberg formation. Mr. G. G. Holmes (36), who has studied the occurrence of the Red Granite and Waterberg formation in the field over wide areas, maintains that the latter formation is younger than the Red Granite, and one of the strongest arguments which he has advanced in support of this contention is that at Rietfontein and Sterkfontein in the Northern Transvaal, beds of conglomerate are found at the base of the Waterberg formation composed almost entirely of pebbles of a compact felsitic rock, similar to that which, as he has before pointed out, forms the topmost portion of the igneous complex of rocks known as the Plutonic series of the Bushveld. However, it may be that these pebbles have been derived from some earlier felsitic rocks, older than the Plutonic series of the Bushveld; or, possibly the Red Granite was intruded, in the form of a laccolite into the Waterberg beds during the laying down of this latter formation; and, here and there, portions of the laccolite might have penetrated to the surface, and so pebbles of its upper felsitic portions might occur in some of the more recent conglomerates of the Waterberg formation; and, the conglomerates referred to by Mr. Holmes may only apparently, but not actually, belong to the base of the formation, owing to the lower beds being absent in this particular locality. Dr. Molengraaff (60), while inclined to the opinion that the Red Granite, together with the other rocks of the Plutonic series of the Bushveld, were intruded in the form of a laccolite between the Pretoria and Waterberg formations, the former constituting the floor and the latter the roof of the laccolite, reserves a final opinion until further researches furnish sufficient data. There is, however, no doubt that the Red Granite is older than than the Dwyka Conglomerate and Coal-Measures since rocks derived from those belonging to

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the Plutonic series of the Bushveld have been found in the Dwyka (65). I have myself found boulders of typical coarse-grained Red Granite, in which granophyric structure was distinctly discernable with a pocket lens, in Dwyka breccia, on the farm Zonderwater [173] which adjoins the farm Elandsfontein [85], on which the Premier Diamond mine is situated; and, as granite does not occur to the south, but, similar coarse-grained Red Granite does occur to the north, this supports the theory that the movement of the ice-sheets to which we owe the Dwyka was from north to south.

The Plutonic series of the Bushveld really consists of a complex of igneous rocks, containing both acid, intermediate, and basic types, such as the Red Granite, various syenites, felsites, granophyres, basic amygdaloidal rocks, serpentine rocks, norites, peridotites, etc., covering an area of some 23,000 square miles (66). These rocks, while all belonging to the same period of eruptive and intrusive activity, are not all of exactly the same age, but belong to different stages of this period. Dr. Molengraaff (61), in speaking of the history of the intrusions of these rocks, has called attention to the fact that the "distribution of the magma was such that towards the periphery it became more and more basic, while towards the central and higher part, this magma was acid and granitic." Moreover, the Red Granite itself, which represents the acid type of this igneous complex, is not all of contemporaneous origin, though belonging to the same family. Mr. E. J. T. Jorissen (44) has recorded the occurrence of two varieties on the farm Vlaklaagte [39]; the one, which he terms the older, is the ordinary coarse-grained red granite, and, the other, which he calls the younger, is a rock of somewhat different structure, in which the quartz has a different form of crystallisation; the latter he terms a granulite, using the word in the sense in which it is employed by French

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geologists. May it not be, as Dr. Molengraaff has suggested to me, that this coarse-grained variety, which is the typical Red Granite of the Bushveld and which is characterised by its granophyric structure, is an intermediate type occuring between the upper felsitic portion of the original granitic mass and a deeper-seated portion; and, that the other granite, which Mr. Jorissen terms a granulite and which Dr. Molengraaff terms a panidiomorphic granite, represents this deeper-seated variety, which, here and there, has been brought to the surface by after-intrusions. This would certainly explain why, owing to more rapid cooling, granophyric structure, due to the simultaneous crystallisation of quartz and felspar, occurs in the former type while in the latter type, as a consequence of gradual cooling, the various minerals have been able to crystallise in idiomorphic forms. The fact that on either side of this occurrence of panidiomorphic granite first the granophyric type is met with and then still further away the felsite occurs certainly seems to support this view. Two varieties, belonging to different stages of eruption, also occur on the farm Roodepoortje, on which the Albert Mine is situated. The older is the granophyric Red Granite; and, the other is a fine-grained granite, containing porphyritic blebs of quartz and porphyritic crystals of felspar, usually having corroded outlines.

Further research may very probably prove that different varieties of the Old Granite occur which differ somewhat in age, although belonging to the same period of eruption.

As in the Cordilleras of the Andes of Chile in South America (3), so here in South Africa the red potash-granite is younger than the white soda-granite.

The modern theory of the mode of origin of granite is that it is a deep-seated or abysmal rock which, in the

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presence of superheated water, has consolidated under pressure due either to an atmosphere densely loaded with vapours in the earliest ages, or to overlying rock. Moreover, as Scheerer (73) has observed, there exist in granite various minerals which, so far as our knowledge goes, could not have consolidated save at a comparatively low temperature; and he concluded that granite, though it may have possessed a high temperature, cannot have solidified from simple igneous fusion, but must have been a kind of pasty mass containing a considerable proportion of water. In such cases its presence at the surface is due to the removal by denudation of masses of rock under which it originally solidified, and into which it may be intrusive by subsequent protrusions.

This explanation will apply in the case of the Old Granite; but, it would seem that this is not the only way in which granite may be formed, and that we owe the newer Red Granite to somewhat different causes.

Sir Archibald Geikie (13) states that granite may occur "connected with true volcanic rocks, and forming, perhaps, the lower portion of masses which flowed out at the surface as lavas. In the tertiary volcanic region of the west of Scotland, masses of granite and granophyre have pierced the sheets of sub-ærial basalts, and must have risen near to, if they did not actually reach, the surface. They prove that granite is not necessarily, though usually an abysmal rock." This helps to explain the occurrence of the Red Granite with its associated complex of igneous rocks.

Dr. Molengraaff (68) has, I think, arrived at the correct solution of its mode of origin when, in his Annual Report for 1898, as State Geologist to the late South African Republic, he writes: "I consider the Red Granite, as forming a portion of an enormous sheet, although

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decidedly of a micro-pegmatite structure, has much in common with that of the plutonic rocks, which is my justification for still retaining the name Granite. The apparent contradiction disappears if we take into consideration that we have here to deal with a stream of acid—probably very viscous—lava of enormous extent and thickness. This explains how the intra-liquid portion would cool only slowly, and thus acquire the characteristic structure of plutonic rocks . . . . The bed of the Pienaar's river on the farms Baviaanspoort [470], Leeuwfontein [320], Zeekoegat [(287], and Roodeplaat [314] offers excellent opportunities for the study of the earlier results of the above-mentioned eruptive activity, followed by the outflow of a colossal stream of granitic lava, which in its central and lower portions consolidated to a 'granite' with micropegmatitic structure, the portion nearer the surface, however, furnished rocks belonging to the quartz-porphyry and felsite-porphyry group." More recently, instead of a sheet, he speaks (66) of the intrusion of a magma, rich in soda, which might be of the nature of a laccolite. However, whether portion of an enormous sheet or of a laccolite the origin of the granite, in either case, is the same.

Dr. Molengraaff (62), points out that the Red Granite occupies the centre of the vast plutonic area of the Bushveld, whilst the other types are confined to the peripheral region, the basicity of the rocks increasing from the centre to the periphery. This may be due, or partially due, to segregation occurring in the magma. I think it likely that this segregation mostly occurred in the magma, before eruption, according to specific gravity. In this way, the acidity of the magma would increase from below upwards owing to the specific gravity decreasing as the magma became more and more acid. Thus representatives of the central and earlier stages of eruption would be the most acid, and later products,

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which would select the marginal portion of the already erupted mass for channels of ascension as offering lines of least resistance, would be more basic; until the final marginal portions would be represented by the most basic varieties of rocks. It is in accordance with this theory that I consider the contents of the diamondiferous pipes and vents (which are of an extremely basic character) occurring on the edge of the Bushveld to the north-east of Pretoria, as representing the final expiring stages of that period of eruptive activity to which we owe the Plutonic series of the Bushveld. If this be so, I see no reason why other diamondiferous pipes or vents should not exist along, or in close proximity to, any of the marginal portions of this igneous complex. All the diamondiferous pipes or vents so far discovered in the Transvaal are situated in this district; and, occur either in igneous rocks belonging to the Plutonic series of the Bushveld or in the uppermost beds of the Pretoria formation; and, in every case, very near the junction of the two, which certainly lends support to this theory.

"Floating-reef" consisting of Waterberg quartzite and conglomerate occurs in the Premier pipe clearly indicating that the "blue ground" is younger than the Waterberg formation; so that if the intrusion of this diamondiferous matter belongs to a portion of the same period as the Bushveld Plutonic series it follows that this series must necessarily be of more recent date than the Waterberg formation.

One very interesting fact Dr. Molengraaff (63) mentions, in connection with this period of plutonic activity, is that the strata of the Black Reef, Dolomite, Pretoria, and Waterberg formations, at a certain period, sank under the weight of the intrusive masses, and consequently the dip of these beds is everywhere directed towards the Bushveld.

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Economically, the Old Granite has not, up to the present, proved of much importance, although a small amount of gold has been won from quartz veins occurring in it, as, for example, in the Zoutpansberg district.

On the other hand, it would seem that the area occupied by the Red Granite and its associated rocks is destined to be a country of very considerable commercial importance. In this area true fissure veins have formerly been worked for silver; but not with any great success. Galena lodes also occur. Cobalt is found at Kruisriver [85] in the Middelburg district; and, also at Balmoral. In both cases the ore is smaltite, which at the latter place occurs in pegmatite veins (40) within the zone of contact metamorphism of an adjacent boss of Red Granite. Iron, in the form of magnetite, containing from 45 to 60 per cent. of metallic iron, occurs as a segregation product from norite (62), as for example at Magnet Heights, in the Lydenburg district; and, at Onderstepoort, some 9 miles north of Pretoria. All these iron deposits contain a certain amount of titanium, varying from some 3 to 15 per cent. Doubtless the time will come when it will pay to exploit them.

Lately, much attention has been attracted to the Bushveld, owing to discoveries of tin. In 1903 tin was discovered on the farm Enkeldoorn [373], some 40 miles to the north-east of Pretoria, and a great amount of development work has since been done with very satisfactory results. The tin occurs in lodes, striking some 6° west of north and east of south, in the Red Granite, which is here very coarse-grained but still of the granophyric type. According to Mr. H. D. Griffiths, the consulting engineer to the Bushveld Tin Mines who own the farm, the tin occurs as cassiterite in pegmatite or aplite veins, composed of quartz and orthoclase, with occasional flakes of muscovite. In the early part of 1905 tin was discovered

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in the same neighbourhood, about 8 miles to the north-east of Enkeldoorn, on the farm Vlaklaagte [39]. Here the cassiterite occurs in quartz veins and in belts of greisen in the Red Granite. Two types of granite occur: the typical Red Granite, characterised by granophyric structure; and, the later panidiomorphic Red Granite. There are two series of fissures, the one running approximately north and south (magnetic), and the other striking some few degrees north of east and south of west. The latter are the ones in which the original discovery occurred, and these pass from one variety of granite into the other. The greisen lodes consist of granite altered, by pneumatolytic action, into greisen in the immediate neighbourhood of the original fissures; the alteration and the tin-stone impregnation becoming less and less as the distance on either side of the places where the original fissures were situated increases. Local enrichment occurs here and there and is probably due to later hydrothermal action. Cassiterite has also been discovered near the old Albert Silver Mine, on Roodepoortje, about 9 miles south-east of Enkeldoorn. Here it occurs as an impregnation in a series of east and west acid dykes in the porphyritic Red Granite which has been previously mentioned as occurring on this farm. Here, I have seen crystals of tourmaline developed on the faces of joints in these dykes, clearly indicating the part that has been played by pneumatolytic agencies. Moreover, Dr. Molengraaff tells me he found molybdenite on Vlaklaagte and fluorite on Enkeldoorn, both suggesting the action of the same agencies.

If the diamondiferous pipes, occurring to the north-east of Pretoria, be considered as associated with the same period of eruptive activity to which we owe the Plutonic series of the Bushveld, then the economic importance of this complex of rocks is enormously augmented. The output of diamonds for this district for the last six months of 1902 was 1064·5 carats valued at £2402; for the year

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1903 it was 174,976·44 carats, having a total value of £239,854; for 1904 it was 884,330·71 carats, of the total value of £1,150,873; and, for the first four months of 1905 the output was 336,413.07 carats valued at £386,920. The Premier (Transvaal) Diamond Mine is mainly responsible for this large production. The pipe area of this mine is estimated at about 3,500 claims of 900 square (Cape) feet (†). The Company owning the mine was registered in December, 1902; and, the output for the same month was 187¾ carats; for the year 1903 it was 150,416·5 carats; for 1904 it was to 854,823·5 carats; and, for the first six months of 1905 it was 450,917.5 carats.

Very little work has as yet been done on the Bushveld which covers a total area of some 23,000 square miles, and it is impossible to say what wonderful discoveries may, perhaps, yet be made.

Before leaving this subject, I would like to say a few words about the tonalite occurring as intrusive sheets in the Dolomite on the far East Rand (‡), some 40 miles south of the southern edge of the igneous complex of rocks of the Bushveld; and, also about certain rocks occurring on the farm Zonderwater [173], adjoining the farm Elandsfontein [85], on which the Premier diamond mine is situated. The first-named rock is granitic in texture and varies from grey to red in colour, but is usually the latter. Under the microscope, it is seen to consist of a holocrystalline aggregate of lath-shaped crystals of plagioclase felspar, slightly kaolinised; a small amount of orthoclase; green fibrous hornblende; yellow

(†) 1 Cape foot=1.033 English feet.

(‡) Drs. Hatch and Corstorphine in their paper entitled "The Geology of the Bezuidenhout Valley and the District East of Johannesburg" (Trans. Geo. Soc. S.A., Vol. VII, part ii) mention the occurrence of a dyke of similar rock near the Geldenhuis Estate Mine, and suggest that the site of this dyke is one of the fissures from which the material of the above sheets was erupted.

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and greenish-brown micas; some chlorite; interstitial quartz; and, occasionally, a little epidote. A tendency to granophyric structure is observable in places.

The latter rocks cover an area of about 3¾ miles on the farm *Z*onderwater. Occupying the whole of the central portion of the farm, they extend away beyond the northern and southern boundaries. They occur at a constant horizon between the Pretoria and Waterberg formations. The white ripple-marked quartzites of the former outcrop on the western portion of the farm, and dip at a low angle in an easterly direction. On the eastern side of the farm, outcrops of conglomerates and purplish to dark red quartzites of the Waterberg formation occur, which also dip at a low angle in an easterly direction. The central portion of the farm is largely covered by surface soil, and only here and there do bold outcrops of igneous rock occur, though there are numerous small and inconspicuous ones. The igneous rocks, apparently, all belong to one and the same intrusion. A very characteristic feature is the great variations which are to be found both in colour and texture within short distances. The two extremes of colour are red and green, and intermediate shades occur of dull red and dull green, merging into various shades of dark grey. The microscope, however, shews that they all belong essentially to one and the same type of rock. In one place, near the south-east farm-beacon, an outcrop occurs of a rather different type of rock. This is a fine-grained rock, dull purple in colour and resembling a rhyolite; it may, perhaps, represent the original uppermost portion of this intrusive mass. The red and the green varieties have a granitic texture; the duller coloured varieties are fine-grained and compact. Under the microscope, they are all seen to consist of a holocrystalline aggregate of plagioclase and red orthoclase felspar, somewhat turbid through kaolinisation; yellow and light green micas;

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a little quartz; chlorite; black oxide of iron and, occasionally, a little augite. The granophyric structure varies from the incipient to the well-developed stage; but, the latter is the more usual. On the geological map accompanying the Annual Report of the Geological Survey for 1903, the greater proportion of these rocks have been mapped as diabase and the remainder as felsite. However, on pages 25 and 26 of the report it is explained that "the term diabase is here used rather with reference to the general appearance and behaviour of the rocks in the field than in any strict petrological sense." Also that "the occurrence of micro-pegmatite as a constituent of this rock is a very common feature." Further that "the tendency to a transition to felsitic forms is especially noticeable in and about the areas represented on the map at the east and west ends of the southern boundary of the farm Zonderwater [173]". I have preferred to use the term granophyre to designate these rocks as this name at once indicates their chief structural features, as well as suggests their relation to the typical Red Granite, which is characterised by the presence of micro-pegmatite.

Below in column I. is given the analysis of the typical red variety of granophyre from the eastern portion of the intrusive mass on Zonderwater; and in column II. the analysis of the typical green variety from the western portion. In column III. is the analysis of the red tonalite from typical pieces taken, here and there, between the depths of 525 and 583 feet from No. 2 borehole on the farm Palmietkuil [61] on the far East Rand. This rock is almost identical, in the hand specimen, with the red variety of granophyre of column I.

It will be noticed that the rock from the eastern portion of the farm near the top of the Pretoria formation is of a more basic character than that from the western portion, situated at a slightly higher geological horizon near the base of the Waterberg formation, indicating that a certain amount of magmatic segregation has taken place.

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	I.	II.	III.
SiO_2	55.00	59.63	62.20
TiO_2	—	—	—
Al_2O_3	16.83	16.18	16.58
Fe_2O_3	10.19	7.34	5.00
FeO	3.60	2.66	2.80
MnO	—	tr.	tr.
CaO	5.91	8.63	4.40
MgO	5.16	1.91	4.20
K_2O	0.90	1.23	1.80
Na_2O	1.00	1.80	2.10
P_2O_5	0.67	0.13	0.37
FeS_2	0.225	tr	0.17
H_2O	—	—	—
	99.485	99.51	99.62
Sp. Gr.	2.774	2.880	2.686

These granophyres occur on the edge of the Bushveld occupying the same geological horizon as the Plutonic series of the Bushveld; they exhibit the micro-pegmatitic structure so characteristic of the Red Granite of this series, to which there can be no doubt that they also belong.

As regards the tonalite Dr. Hatch (21) has already suggested that this rock, on account of the similarity in petrographical habit, may be connected in origin with the "Red Granite" intrusions of the Bushveld; and, the above comparisons of the rock with those of Zonderwater can leave no doubt that it forms a portion of the same igneous complex of rocks as those which occur in the Bushveld.

THE END.

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WORKS OF REFERENCE.

ABBREVIATIONS.

Q.J.G.S. Quarterly Journal of the Geological Society, London.

B.S.G. Bulletin de la Société Géologique de France.

T.G.S.S.A. Transactions of the Geological Society of South Africa.

P.G.S.S.A. Proceedings of the Geological Society of South Africa.

M.P.I.C.E. Minutes of Proceedings of the Institution of Civil Engineers, London.

J.P.S.A.A.E. Journal of Proceedings of the South African Association of Engineers.

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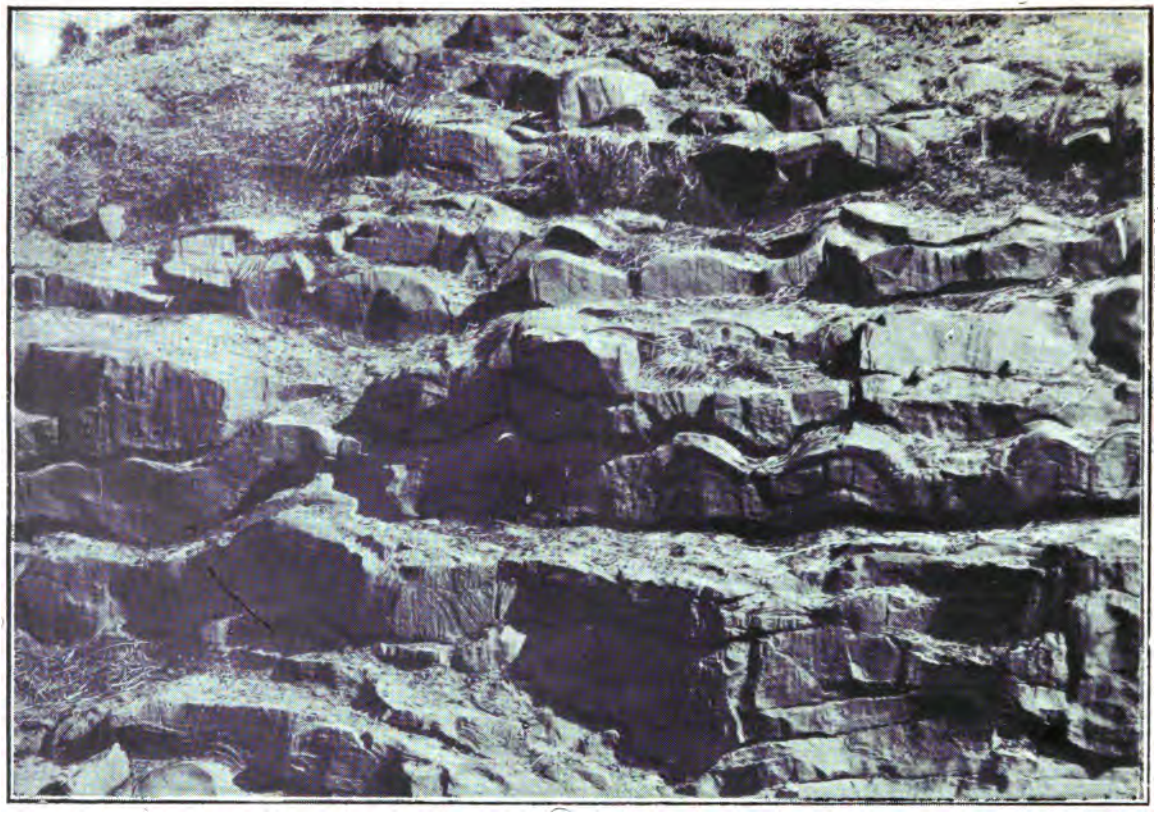
PLATE I.



Curious "Saddle-like" Outcrop of Dolomite, Suikerbosch River.

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PLATE II.

Curious "Saddle-like" Outcrop of Dolomite, Suikerbosch River.

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PLATE III.

Black Reef Quartzite resting unconformably on the Old Granite. Teangkop, Bechuanaland.

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PLATE IV.

Black Reef Quartzite resting unconformably on the Klipriversberg Amygdaloidal Diabase. Suikerbosch River; about 3 miles east of Vereeniging.

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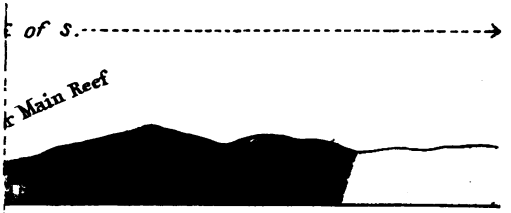

Old (or Basement) Granite....

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